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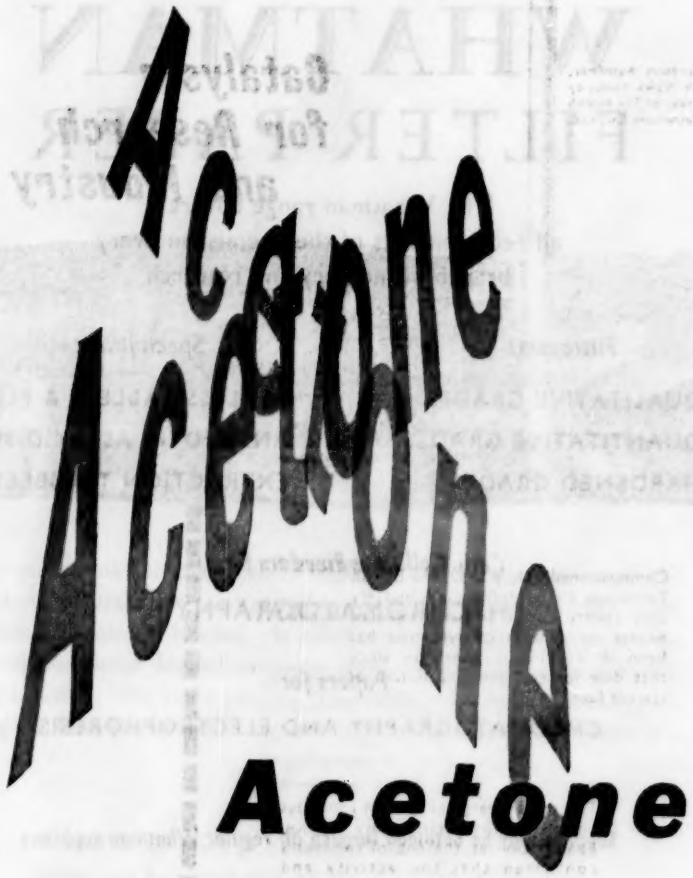

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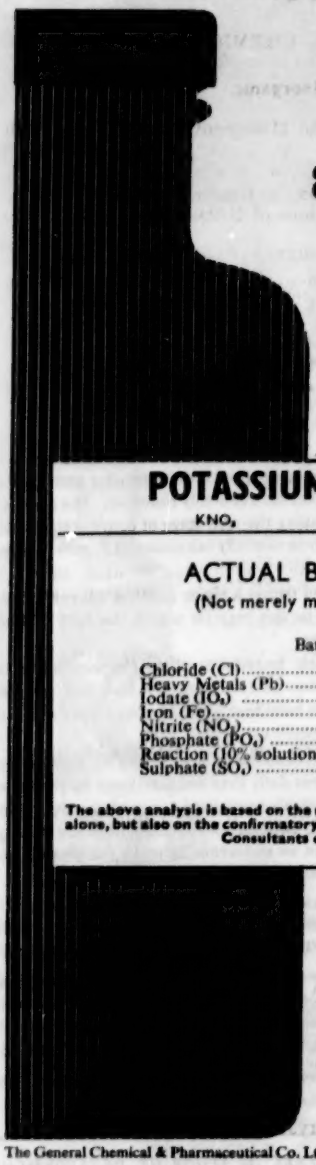

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(Not merely maximum impurity values)

Batch No. 75401

Chloride (Cl)	0·0005%
Heavy Metals (Pb)	0·0002%
Iodate (IO_3)	no reaction
Iron (Fe)	0·00006%
Nitrite (NO_2)	no reaction
Phosphate (PO_4)	0·0004%
Reaction (10% solution)	pH 7·0%
Sulphate (SO_4)	0·0005%

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The Kinetics and Mechanism of the Reactions of the Halogenotrimethylsilanes with Methylmagnesium Halides.

By A. F. Reid and C. J. Wilkins.

[Reprint Order No. 6025.]

The kinetics of reactions of the halogenotrimethylsilanes with methylmagnesium chloride, bromide, and iodide have been followed in ether solution by iodometric titration of the Grignard reagent. With initial concentrations of 0·2—0·4M the reactions obey second-order kinetics until a second magnesium halide-rich layer separates. The effect of a polar substituent in the halogenosilane has been examined using chloro(chloromethyl)dimethylsilane and by comparing the behaviours of chlorodimethylphenyl- and -*p*-tolylsilane.

The results indicate a reaction mechanism involving magnesium–halogen co-ordination of the type $Me_3SiX \rightarrow Mg(Me)X$, associated with transfer of the methyl group and simultaneous rupture of the silicon–halogen bond.

No direct information about the mechanism of the reaction between Grignard reagents and silicon halides is available; we accordingly sought kinetic evidence, especially as few reactions of silicon halides or of Grignard reagents have hitherto been subjected to quantitative kinetic study. However, 90% yields of pure tetra-alkylsilanes have been obtained from triethylfluorosilane or tri*iso*butylfluorosilane and methylmagnesium iodide (Eaborn, *J.*, 1949, 2755) and from chloro(chloromethyl)dimethylsilane and methylmagnesium bromide (Whitmore, Sommer, and Gold, *J. Amer. Chem. Soc.*, 1947, **69**, 1976).

In the systems for which results are given in Tables 1 and 2 the reactions followed second-order kinetics until a relative increase in speed associated with the separation of a second liquid phase. With 0·2—0·4M-solutions in ether this usually did not occur until the reaction was at least half completed. In the reactions of fluorotrimethylsilane with methylmagnesium bromide and iodide, early separation of crystalline magnesium halide did not disturb the kinetics. It was not possible to obtain comparable data on the systems bromotrimethylsilane–methylmagnesium chloride or iodotrimethylsilane–methylmagnesium bromide probably owing to the occurrence of halogen exchange as well as methylation. The reaction between iodotrimethylsilane and methylmagnesium chloride was not examined since a similar complication seemed likely. The system fluorotrimethylsilane–methylmagnesium chloride failed to yield significant results owing to the separation of a second liquid and a solid phase very early in the reaction.

The Nature of Ethereal Solutions of Grignard Reagents.—The reagents are associated (probably dimeric) in ether (Meisenheimer and Schichenmaier, *Ber.*, 1928, **61**, 721), and there is a slight electrolytic dissociation, probably to give the ions RMg^+, $RMgX_2^-$, MgX^+, and R_2MgX^- (Evans and co-workers, *J. Amer. Chem. Soc.*, 1936, **58**, 721; 1942, **64**, 2865; Young and Roberts, *ibid.*, 1946, **68**, 1472). There is no evidence for the existence of an appreciable concentration of carbanions in the solutions, but the possibility that the mechanism requires the methyl ion cannot be excluded.

Recent evidence (Noller and co-workers, *ibid.*, 1937, **59**, 1345; 1940, **62**, 1749; 1942, **64**, 2509; Stewart and Ubbelohde, *J.*, 1949, 2649; Kullmann, *Compt. rend.*, 1950, **231**, 866) does not favour the existence, in solutions of alkylmagnesium bromides and iodides, of the equilibrium: $2RMgX \rightleftharpoons MgR_2 + MgX_2$ leading to the formation of dialkylmagnesium (Schlenk and Schlenk, *Ber.*, 1929, **62**, 920). For several reactions as between methylmagnesium iodide and acetone (Aston and Bernhard, *Nature*, 1950, **165**, 485), and phenylmagnesium bromide and valeronitrile (Gilman and Brown, *J. Amer. Chem. Soc.*, 1930, **52**, 1181) or benzonitrile (Swain, *ibid.*, 1947, **69**, 2306), kinetic or other evidence excludes the reactivity of the Grignard reagent's being due to dialkyl- or diaryl-magnesium. In ether " methylmagnesium chloride," however, differs from the bromide and iodide in being deficient in halogen (Cope, *ibid.*, 1935, **57**, 2238). Hence this solution must contain either free dimethylmagnesium or some complex having a magnesium atom linked to more than

one methyl group. The kinetic behaviour of methylmagnesium chloride towards chlorotrimethylsilane does not suggest any peculiarity arising from the halogen deficiency, but comparison with other systems should be treated with reserve.

The Reaction Mechanism.—There is no evidence for ionisation of the trialkylhalogenosilanes in ether. Gingold, Rochow, Seyferth, Smith, and West (*ibid.*, 1952, **74**, 6306) report these solutions to have no detectable conductivity and this was confirmed in the present work.

It is probable that the transition state contains halogen from both the Grignard reagent and the silane. Otherwise, if the Grignard reagent (or *mutatis mutandis* the silane) participated through a halogen-free component, then, subject to the restriction of second-order kinetics, the rates of reaction of each silane with methylmagnesium bromide and iodide at a particular temperature should be in a constant ratio; but this was not found to be so.

Mechanisms having the following broad characteristics may be considered.

(I) *Attack on silicon with simultaneous breaking of the* Si–X *bond.*

(II) *Attack on silicon to give a quinquecovalent complex* $(Me)_4SiX^-$ (cf. Price, *ibid.*, 1947, **69**, 2600; Swain, Esteve, and Jones, *ibid.*, 1949, **71**, 965; Gilman and Dunn, *ibid.*, 1951, **73**, 3404). The rate-determining step may be (*a*) formation of the complex; or its decomposition through either (*b*) spontaneous elimination of a halide ion, or (*c*) removal of halogen by a magnesium centre (*e.g.*, MgX^+, following initial attack by Me^-).

(III) *Initial co-ordination of halogen by magnesium.* The slowest step may be (*a*) formation of the complex by attack of a magnesium centre carrying a methyl group, or (*b*) decomposition through intramolecular transfer of the methyl group from magnesium to silicon. Alternatively the slowest process may be (*c*) reaction between Me^- and a complex $(Me)_3SiX \rightarrow MgX^+$.

The experimental results enable us to reject several of these possibilities. The absence of any marked influence of the polar chloromethyl group on the activation energies (Table 1) discounts steps II*a*, II*b*, II*c*, and III*a*. Mechanisms of class I (as also II*a* and II*b*) could

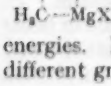
TABLE 1. *Activation functions.*

	Activation energies (kcal. ± 0·6)			Activation free energies at 0° c * (kcal. ± 0·05)		
	MeMgCl	MeMgBr	MeMgI	MeMgCl	MeMgBr	MeMgI
Me_3SiF	—	8·8	13·5	—	20·86	21·04
Me_3SiCl	8·0	8·1	10·6	21·20	20·47	20·35
Me_3SiBr	—	10·6	11·3	—	20·21	19·32
Me_3SiI	—	—	9·2	—	—	18·46
$Cl{\cdot}CH_2{\cdot}SiMe_2{\cdot}Cl$	8·3	11·5 ± 2	9·8	19·40	19·72	20·52

	$-T\Delta S$ at 0° c (kcal. ± 0·7) ($\log_{10} A$ in parentheses)		
	MeMgCl	MeMgBr	MeMgI
Me_3SiF	—	12·0(3·1)	7·5(6·7)
Me_3SiCl	13·1(2·2)	12·3(2·9)	9·2(5·0)
Me_3SiBr	—	9·6(5·0)	7·9(6·4)
Me_3SiI	—	—	9·2(5·3)
$Cl{\cdot}CH_2{\cdot}SiMe_2{\cdot}Cl$	11·1(3·9)	8·1 ± 2(5·9)	10·6(4·2)

* Calc. from the expression $-\Delta F = 2{\cdot}303RT\,[\log(RT/Nh) - \log k]$

hardly account either for the small range of activation free energies within the halogenosilane series or for the steric sensitivity of the reaction (Eaborn, *J.*, 1952, 2840) to the sizes not only of the alkyl groups but also of the halogen atoms of both the silane and the Grignard reagent. The remaining mechanisms III*b* and III*c* are free from these objections provided that formation of the silicon–carbon bond and rupture of the silicon–halogen bond are simultaneous. For III*b* the rate-determining step would represent the concerted reorganisation of a cyclic transition state (inset). This mechanism is preferable to III*c* in not requiring the methyl ion for which there is no independent evidence, and moreover it can provide an explanation of trends in activation energies. It is closely similar to the mechanism offered by Swain (*loc. cit.*) on quite different grounds for the reaction between phenylmagnesium bromide and benzonitrile.



The decreasing activation energies from the fluoro- to the iodo-silane in the methylmagnesium iodide series reflect the contribution from the breaking of the silicon–halogen bond. For the methylmagnesium bromide reactions activation energies are lower and the decreasing trend is lost. Breaking of the silicon–halogen bond must therefore be less important in this series, as would be expected for a cyclic transition state since increasing electronegativity of the halogen atom of the Grignard reagent would assist rupture of this bond but hinder release of the methyl group from the magnesium atom.

The accumulation of magnesium halide in the solution during the reaction does not produce any detectable kinetic effect arising from its polarity or from interaction with remaining methylmagnesium halide (Stewart and Ubbelohde, *loc. cit.*) but mutual cancellation of such effects is possible. However, the reaction is probably insensitive to solvent polarity since in several systems : Me_3SiF–MeMgBr, Me_3SiF–MeMgI, and Me_3SiCl–MeMgCl an increase in the concentration of halogenosilane from 0·2—0·3M to 0·7—1·0M did not alter the rate constants. Hence, within the limits of available evidence, the rate-determining step does not involve a net change in the formal charge on any atom. This again favours mechanism III*b*.

Trends in entropies of activation receive plausible interpretation on the basis of halogen interactions associated with a magnesium co-ordination process as in mechanisms III*b* or III*c*. The more negative value for the activation entropy of the reaction of each silane with methylmagnesium bromide than with methylmagnesium iodide may be related to the higher polarities induced in the silicon–halogen bonds through co-ordination with the former, which in turn produces a greater orientation of solvent molecules. Chloro(chloromethyl)dimethylsilane shows a higher entropy of activation than chlorotrimethylsilane in the reactions with methylmagnesium chloride and bromide. This may likewise be attributed in part to a reduction in the polarity of the silicon–halogen bond by the chloromethyl substituent, in so far as this reduces repulsions between the halogen attached to silicon and the groups on magnesium. It is suggested that the reverse trend for the corresponding reactions with methylmagnesium iodide is due to steric interference between the chloromethyl group and the iodine atom which more than offsets the polar effect.

Variants of mechanism III*b* require mention. Co-ordination by magnesium centres of the anions Me_2MgX^- or $MeMgX_2^-$ is unlikely, but there seems no reason to exclude direct participation of the dimer in the reaction. Certain conditions could reduce kinetic complications arising therefrom. Thus any shift in the equilibrium between monomer and dimer as the reaction proceeds could be reduced by co-ordination of accumulating magnesium dihalide with the remaining unreacted monomer. Also, as apart from the possible effects of co-ordination, similarity in the reactivities of the carbon–magnesium bonds of the monomer and dimer would lessen deviation from second-order kinetics.

*The Reactions of Chlorodimethylphenylsilane and Chlorodimethyl-*p*-tolylsilane with Methylmagnesium Iodide.*—Activation functions are summarised in Table 2 which includes data on the reaction of chlorotrimethylsilane with the same Grignard reagent.

TABLE 2.

Silane	ΔH (kcal. ± 0·6)	ΔF (kcal. ± 0·05)	$-T\Delta S$ (kcal. ± 0·7)	$\log_{10} A$
Me_3SiCl	10·6	20·35	9·6	5·0
$PhSiMe_2Cl$	11·2	20·12	8·9	5·6
$C_7H_7{\cdot}SiMe_2Cl$	10·1	20·19	10·1	4·7

The figures for chlorodimethylphenylsilane and chlorotrimethylsilane are sufficiently similar to warrant the assumption that the introduction of an aromatic substituent does not alter the reaction mechanism. Values for the phenyl and *p*-tolyl compounds are also rather similar and the differences are hardly outside experimental error. Nevertheless, the entropy of activation is almost certainly raised by the presence of the electron-releasing *p*-methyl group, as would be expected on the basis of the mechanism proposed.

If any conclusion can be drawn from the comparative figures (Table 2) for chlorotrimethylsilane and chlorodimethylphenylsilane it is that the phenyl group attached to

silicon is more electronegative than a methyl group (cf. Roberts, McElhill, and Armstrong, *J. Amer. Chem. Soc.*, 1949, **71**, 2923).

Experimental

The apparatus, based on a 300-ml. three-necked flask, is shown in Fig. 1. The funnel and burette carried two-way taps connected to a nitrogen supply as shown.

After the assembly had been flushed with nitrogen the Grignard reagent was introduced from a 240-ml. transfer bulb (*D*, Fig. 2), attached at *A*, by opening the lower tap *E*. For withdrawal of samples for analysis a suitable extra pressure of nitrogen was maintained in the apparatus and the burette filled by opening the tap *B* to the atmosphere. The tap was then reversed to the nitrogen supply, thus allowing the solution to level off to the side-arm. This known volume was run into the reagent solution for analysis. A suitable quantity of halogenosilane diluted to a known volume with ether was introduced into the funnel and brought to bath temperature by circulating thermostat liquid through the jacket. The reaction was started by opening tap *C*.

Fig. 1. *Apparatus for following reaction kinetics.*

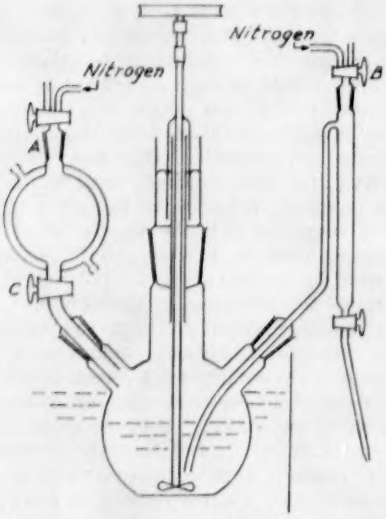
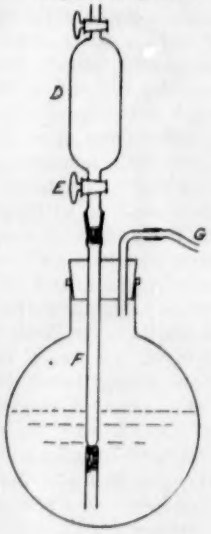


Fig. 2. *Method of transferring Grignard reagent.*



The thermostat bath could be operated from −10° to +30° (±0·03°). Measurements on each system were made over ranges of 20—30°.

Preparation, Storage, and Transfer of Solutions of the Grignard Reagents.—These solutions (0·2—0·4M) were prepared under nitrogen in quantities of 3—4 litres. Redistilled methyl halides were used, care being taken to avoid excess. The solutions were stored in the flasks used for their preparation. A mercury bubbler released undue pressure of ether vapour.

To transfer the solution to the reaction vessel the tube *F* containing a glass-wool filter was inserted through the rubber stopper until its lower end was just above the surface of the liquid. The transfer bulb was fitted to the ground joint at the top of the tube as shown and nitrogen passed into the apparatus at *G* to flush air from the bulb. The lower end of the tube was then pushed beneath the surface of the liquid so that the clear solution was forced into the bulb by the nitrogen pressure. When the bulb was full both taps were closed and this known volume of solution was transferred to the reaction vessel without contact with air.

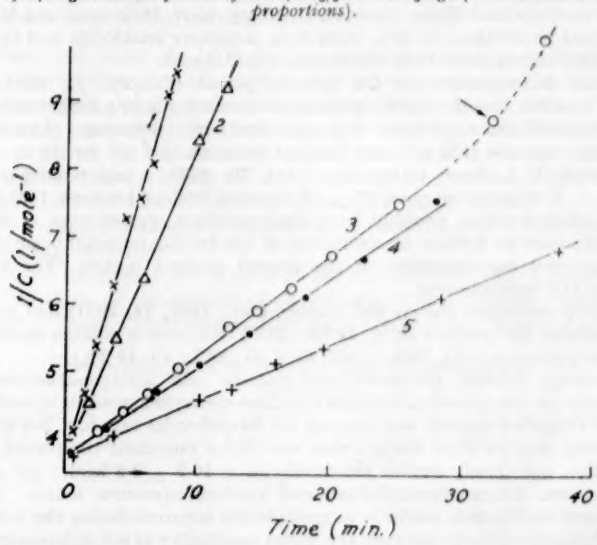
Analysis of Methylmagnesium Halide Solutions.—The iodometric method alone was used for analysis during a reaction but was supplemented by gasometric and acidimetric procedures for the initial analysis of the Grignard reagent. The gasometric method is in theory the most accurate since only magnesium–carbon bonds are estimated, but as each determination is

lengthy the method was used primarily for analysis of each new preparation of methylmagnesium halide. The iodometric method gives results lower (by 5—6% in the present experiments) than those obtained gasometrically (Gilman and Meyers, *Rec. Trav. chim.*, **1926**, **45**, 314; Mackle and Ubbelohde, *J.*, **1948**, 1161) and a correction factor was used to obtain the true molarity of the solution.

The acidimetric method on the other hand, while affording the most precise experimental procedure, gives results somewhat higher than the gasometric, probably because it also estimates any oxy-compounds present. An acidimetric analysis was always made before a run since any variation in the ratio $M_{acid} : M_{iodine}$ would give warning of the solution's having deteriorated. In fact no such difficulty was encountered and this analytical ratio changed very little during several weeks.

With 12 ml. of methylmagnesium halide solution (about 0·25M), acidimetric titrations were reproducible to ±0·4%, and iodometric to ±0·7%. In the latter procedure methylmagnesium

FIG. 3. *Plots of* 1/c *against time for the system* $(CH_3)_3SiBr$–CH_3MgI (*the reactants being in equimolar proportions*).



The scale refers directly to plots 1 and 4. For convenience the remaining curves have been drawn from the same origin, 2 and 5 having been lowered by 0·50 unit and 3 by 1·40 units. Temperatures and rate constants are: (1) 24·8°, 0·670; (2) 20·0°, 0·452; (3) 4·7°, 0·150; (4) 0·2°, 0·127; (5) −3·3°, 0·086. The broken extension to curve 3 shows the typical kinetic effect associated with separation of the second liquid phase which was observed at the point indicated by the arrow.

halide was delivered beneath 25 ml. of a solution (0·45N) of iodine in benzene (see Champetier and Kullmann, *Bull. Soc. chim. France*, **1949**, **53**, 693).

The apparatus for gasometric analysis was as used by Gilman, Wilkinson, Fishel, and Meyers, (*J. Amer. Chem. Soc.*, **1923**, **45**, 150) but having provision for recirculation of the methane through the sulphuric acid bubbler to ensure complete removal of ether vapour.

Results.—Experimental results for runs on the reaction between (equivalent quantities of) bromotrimethylsilane and methylmagnesium iodide, which may be taken as typical, are plotted as $1/c$ against time in Fig. 3. The parameters of the Arrhenius equation $k = A \exp(-E/RT)$ expressing the bimolecular rate constant (l. mole^{-1} sec.$^{-1}$) for each system are included in Tables 1 and 2.

For most of the individual systems the same preparation of Grignard reagent was used throughout. The variation in the individual experimental values of log k from the values defined by the best straight lines of the Arrhenius plots, expressed as a standard deviation over all such systems, was 5½%. This may be compared with the predicted maximum random deviation of 6½%, based on an assessment of the various errors arising from analysis and transfer

of the reactants. The maximum deviation was slightly greater for systems where different preparations of methylmagnesium halide were used since systematic errors would thereby have been introduced, but was always within the predicted deviation of 10%. Experimental errors in the thermodynamic functions for each system are shown in Tables 1 and 2.

There was no evidence that variations in the degree of oxidation of a Grignard reagent, within the range $M_{iodine} : M_{acid} = 0{\cdot}91—0{\cdot}87$, influenced the kinetics. The kinetics were unaltered by using sodium-dried ether either directly or immediately after efficient fractional distillation. Redistillation of each of the silanes was also without effect. It must be mentioned however, that for some reason there was initial difficulty in obtaining reproducible results on the system chlorotrimethylsilane–methylmagnesium bromide, and that the results for the system chloro(chloromethyl)dimethylsilane–methylmagnesium bromide showed a wider scatter than usual.

Preparation of Halogenosilanes.—Most of these compounds were obtained by published methods and were purified to distillation ranges of less than 0·2° unless otherwise stated.

Fluorotrimethylsilane (Booth and Suttle, *ibid.*, **1946**, **68**, 2658) had d_4^0 0·793.

Pure chlorotrimethylsilane (Pray, Sommer, Goldberg, Kerr, DiGiorgio, and Whitmore, *ibid.*, 1948, **70**, 433) could be obtained in 73% yield from antimany trichloride and the bromo-silane (Pray *et al.*, *loc. cit.*), and material from this source was also used.

Photo-chemical decomposition of the iodo-compound (Eaborn, *J.*, 1950, 3084) during preparation was avoided, and the kinetic experiments were made in a darkened room.

Chloro(chloromethyl)dimethylsilane was obtained by refluxing chlorotrimethylsilane (108 g.), sulphuryl chloride (135 g.), and benzoyl peroxide (0·5 g.) for 12 hr. (Contrary to McBride and Beachell, *J. Amer. Chem. Soc.*, **1948**, **70**, 2532, a high-boiling diluent was not found necessary.) Fractionation gave 47 g. of material boiling between 113° and 120°. On re-distillation a small fraction, possibly from decomposition, passed over at 80—90°. After removal of this fraction no further accumulation of low-boiling material occurred on refluxing so that no progressive decomposition of the desired product occurs. The fraction (37 g.) distilling at 115—116° was collected.

Chlorodimethyl-p-tolylsilane (Lewis and Gainer, *ibid.*, 1952, **74**, 2931) had to be repeatedly fractionated to obtain the product (b. p. 216·5—218°) free from a volatile bromine compound (Found, by Mohr's titration : Cl, 19·3. Calc. for $C_9H_{13}SiCl$: Cl, 19·2%).

Halogen Exchange between Halogenotrimethylsilanes and Methylmagnesium Halides.—In kinetic experiments on the system iodotrimethylsilane–methylmagnesium bromide a fast initial disappearance of Grignard reagent, not obeying the second-order rate law, but giving place to a slower second-order process when the reaction was about one-third completed, was observed. This latter reaction was closely similar kinetically ($E = 10{\cdot}9 \pm 0{\cdot}8$ kcal.; $\Delta F = 19{\cdot}3$ kcal.) to the reaction between bromotrimethylsilane and methylmagnesium iodide. It would thus appear that halogen exchange in addition to methylation occurred during the first rapid stage of the reaction. Halogen exchange between the initial reactants was not independently confirmed, but was found to occur between magnesium bromide–diether complex and iodotrimethylsilane in ether, though probably considerably more slowly than in the system iodotrimethylsilane–methylmagnesium bromide itself. The kinetic behaviour of the system bromotrimethylsilane–methylmagnesium chloride was qualitatively similar.

We acknowledge the assistance of Miss M. K. Morris with the initial development of the work, and of Mr. G. H. McLellan with the experiments using chlorodimethyl-phenyl- and -*p*-tolyl-silane. We also acknowledge a grant from the research fund of the University of New Zealand.

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Simple Pyrimidines. Part III. The Methylation and Structure of the Aminopyrimidines.*

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2- and 4-Aminopyrimidine are shown to exist largely in the amino-form, by the comparison of their basic strengths, and ultraviolet and infrared spectra, with those of the corresponding nuclear and extra-nuclear *N*-methyl derivatives [*e.g.*, respectively (I) and (IV*a*)].

The preparation of the nuclear *N*-methyl derivatives involved the methylation of 2- and 4-aminopyrimidine to 1 : 2-dihydro-2- and 1 : 4-dihydro-4-imino-1-methylpyrimidine (I) and (II) respectively. In alkaline solution, the former rearranges to 2-methylaminopyrimidine (IV), whilst the latter is hydrolysed to 1 : 4-dihydro-1-methyl-4-oxopyrimidine.

In Part I (Brown and Short, *J.*, 1953, 331), it was shown that the potentially tautomeric 2- and 4-aminopyrimidine give ultraviolet absorption spectra similar to those of the dimethylamino-analogues, which necessarily possess the amino-structure. Such evidence that these amines in aqueous solution exist largely in the amino-form has been supplemented in the present paper by the measurement of the basic ionisation constants, and the ultraviolet spectra of the corresponding nuclear *N*-methyl derivatives (I and II) of authentic imino-structure. Moreover, the infrared spectra of these amines and their *N*-methyl derivatives show similarly that the amino-forms predominate in the solid state and in solution in non-polar solvents.

Spectroscopy.—The ultraviolet spectra of the cations of 2- and 4-aminopyrimidine are closely similar to those of the cations of the corresponding nuclear *N*-methyl derivatives (Fig. 1, Table 1). This suggests that in both cases a proton is bonded to a nuclear nitrogen

Table 1. *Ultraviolet spectra of 2- and 4-aminopyrimidine and their N-methyl derivatives.*

Pyrimidine deriv.	pK_a (20°)	pH	$\lambda_{max.}$ (mμ)	log $\varepsilon_{max.}$
(Pyrimidine)	1·30 [a]	7·0	238, 243, 271	3·48, 3·51, 2·63
		−0·8 [a]	242	3·74
2-Amino [a]	3·54 [c]	7·0	224, 292	4·13, 3·50
		1	221, 302—303	4·17, 3·60
2-Methylamino [a]	3·82	7·0	234, 306—307	4·23, 3·43
		1	228, 315	4·23, 3·53
2-Dimethylamino [a]	3·96	7·0	243, 318	4·26, 3·35
		1	235, 324—325	4·24, 3·47
1 : 2-Dihydro-2-imino-1-methyl	10·75 ± 0·10 [d]	13	236, 345 [g]	4·19, 3·46
		7·0	222, 301	4·12, 3·63
4-Amino [b]	5·71 [c]	13	233, 268—269	4·26, 3·72
		0	246	4·27
4-Methylamino [a]	6·12	9·0	242, 276—277	4·18, 3·54
		2·1	254	4·20
4-Dimethylamino [a]	6·35	9·3	250, 286	4·22, 3·56
		3·15	262	4·21
1 : 4-Dihydro-4-imino-1-methyl	12·22 ± 0·15 [d]	13 [f]	253, 315 [h, g]	4·21, 2·79
		7·0	250	4·21

[a] Part I (Brown and Short, *J.*, 1953, 331). [b] Boarland and McOmie (*J.*, 1952, 3716). [c] Albert, Goldacre, and Phillips (*J.*, 1948, 2240). [d] Present work; pK_a values are for M/50-solutions, and determined potentiometrically. [e] In 4N-sulphuric acid. [f] Highest pH used with silica absorption cells. 85% of the neutral molecule is present at this pH. [g] The neutral molecules of the imines decomposed rapidly in aqueous solution. Fresh solutions were made up for every measurement at 1 mμ intervals, in the regions of maximum and minimum absorption, and for every five measurements at 5 mμ intervals elsewhere. [h] Shoulder.

atom in cations from 2- and 4-aminopyrimidine. Such a view is supported by the marked differences between the spectra of the cations of the amino-, methylamino-, and dimethylamino-pyrimidines and that of the neutral molecule of pyrimidine itself (Table 1). For if

* Part II, *J.*, 1955, 211.

the proton were bonded to the amino-group, it would be expected that the spectra of these cations would resemble that of pyrimidine (neutral molecule), just as the spectra of aniline and dimethylaniline, so different from that of benzene, become closely similar to that of

FIG. 1. *Cations of 2-amino-* (——) *and 4-amino-pyrimidine* (— — —), *1 : 4-dihydro-4-* (. . . .), *and 1 : 2-dihydro-2-imino-1-methylpyrimidine* (— . — . —).

FIG. 3. *Neutral molecules of 4-amino-* (——), *4-methylamino-* (— — —), *4-dimethylamino-* (— . — . —), *and 1 : 4-dihydro-4-imino-1-methyl-pyrimidine* (. . . .).

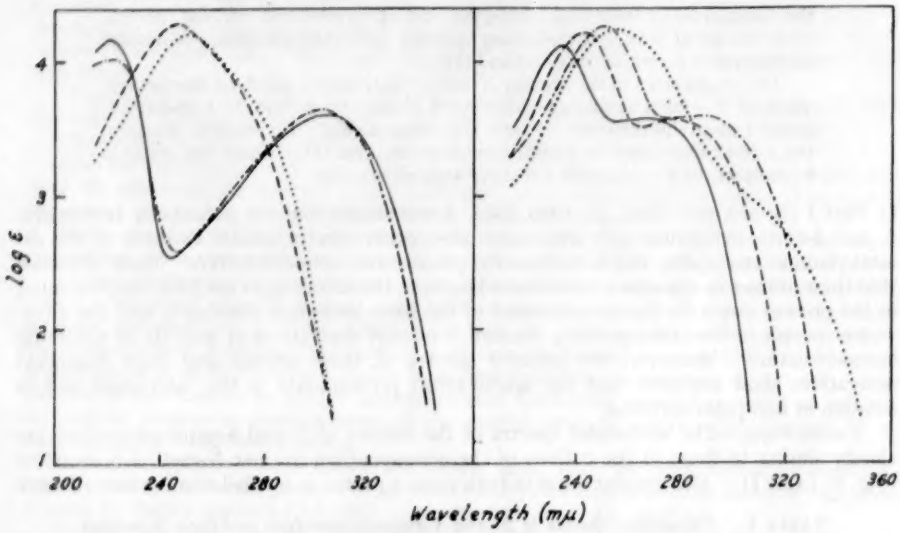
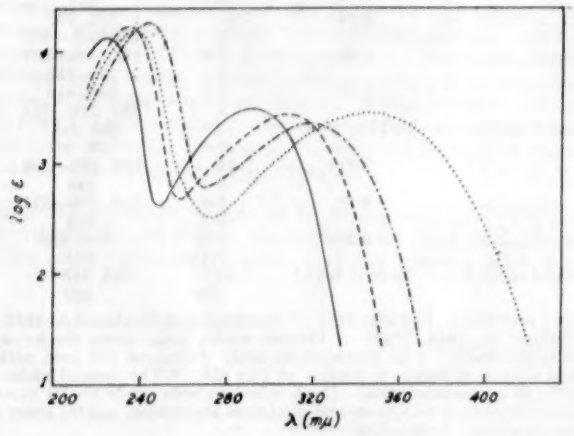


FIG. 2. *Neutral molecules of 2-amino-* (——), *2-methylamino-* (— — —), *2-dimethylamino-* (— . — . —), *and 1 : 2-dihydro-2-imino-1-methyl-pyrimidine* (. . . .).



benzene upon cation formation (Wohl, *Bull. Soc. chim. France*, 1939, **6**, 1312; Landolt–Bornstein, " Tabellen," Ergb. I, p. **443**; Ergb. II, p. **665**; Ergb. III, p. **1377**). Indeed the bathochromic effect of the methyl groups in the dimethylaminopyrimidines is as much in evidence in the spectra of the cations as in the spectra of the neutral molecules (Table 1),

indicating that electronic interaction between the amino-group and the nucleus occurs in the cations, an effect that would not be possible if the proton were bonded to the amino-group.

For the neutral molecules of 2- and 4-aminopyrimidine, it can be seen (Figs. 2 and 3, Table 1) that the ultraviolet absorption curves of these amines are quantitatively displaced further along the wavelength scale from those of the corresponding nuclear *N*-methyl derivatives than from those of the extra-nuclear *N*-methyl analogues, whilst resembling both in qualitative shape. The quantitative features of these spectral data suggest that 2- and 4-aminopyrimidine in aqueous solution exist largely in the amino-form—the wavelength intervals between the two bands of their spectra, 68 and 38 mμ respectively, for example, are more nearly equal to those observed in the case of the dimethylamino-analogues, 75 and 36 mμ, than those found in the cases of the nuclear *N*-methyl derivatives, 109 and *ca.* 65 mμ—although in view of the qualitative resemblance in the shapes of the curves the possibility of some amine–imine tautomerism cannot be dismissed. Moreover, the spectral comparison in the case of 4-aminopyrimidine is to some extent uncertain in that its nuclear *N*-methyl derivative exists only to the extent of 85% neutral molecule at pH 13, the highest pH used with silica absorption cells.

The extent of such tautomerism may be calculated from the ionisation constants of the *N*-methyl derivatives fixed in the amino- and imino-forms (Angyal and Angyal, *J.*, 1952, 1461).

Since $$K_a(\text{amino}) = [\text{amine}][H^+]/[\text{cation}]$$

and $$K_a(\text{imino}) = [\text{imine}][H^+]/[\text{cation}]$$

it follows that

$$K_{\text{tautomeric}} = [\text{amine}]/[\text{imine}] = K_a(\text{amino})/K_a(\text{imino}) \quad . \quad . \quad . \quad . \quad (1)$$

By employing the ionisation constants of the nuclear and the extranuclear *N*-methyl derivatives of 2- and 4-aminopyrimidine (Table 1), it is found that the amine–imine tautomeric constant in aqueous solution is of the order of 10^6 for both these amines (cf. 2×10^5 and 2×10^3 respectively for the corresponding pyridines; Angyal and Angyal, *loc. cit.*).

This value can be only very approximate, as it is necessary in the above calculation to compare the ionisation constant of the dimethyl derivative of the amino-form with that of the monomethyl derivative of the imino-form, and it is unlikely that the ionisation constants are proportionately changed even for equal degrees of methylation. More fundamental is the objection that the methyl derivatives of the tautomers, unlike the tautomers themselves, do not possess a common cation, so that equation (1) is not strictly valid for the methyl derivatives. However, the qualitative significance of equation (1) that the less prevalent tautomer is the stronger base supports the view that 2- and 4-aminopyrimidine exist predominantly in the amino-form.

For 4-aminopyrimidine there is an added uncertainty in the above calculation, as only one of the two possible nuclear *N*-methyl derivatives was available. The other, the 3-methyl derivative, may possibly not be relevant to the present purpose, for the ready and exclusive methylation of 4-aminopyrimidine on the nuclear 1-nitrogen atom, and the similarity of the spectra of the cations of 4-amino- and 4-dimethylamino-pyrimidine and 1 : 4-dihydro-4-imino-1-methylpyrimidine, suggest that the 1-nitrogen atom is the basic centre of these compounds, and thus that the above calculation of an approximate tautomeric constant for 4-aminopyrimidine is valid within the limitations previously discussed.

In the solid state and in non-aqueous solvents 2- and 4-aminopyrimidine similarly exist largely in the amino-form, as is shown by their infrared spectra. Both amines in carbon tetrachloride solution give two strong, sharp bands at 3540 and 3430 cm.$^{-1}$, due to the asymmetric and symmetric stretching modes respectively of the unassociated NH_2 group, and two broad bands at 3320 and 3170 cm.$^{-1}$ due to the same vibration modes of the intermolecular, hydrogen-bonded NH_2 group. The intensities of the broad bands relative to those of the sharp bands increase with the concentration of the amine in solution, and in the solid state only the broad bands are observed (Table 2). 2- and 4-Methylamino-pyrimidine give only one sharp band at 3460 cm.$^{-1}$, and a broad band near to 3260 cm.$^{-1}$

which is concentration-dependent in solution and is alone observed in the solid state. For 4-methylaminopyrimidine the 3460 cm.$^{-1}$ band is a doublet with a spacing of 23 cm.$^{-1}$ between its peaks, suggesting that there is a slight difference between the N–H bond strength of the form in which the methyl group is *trans* to the 5-CH group of the nucleus and the form in which is *cis*, owing presumably to some steric hindrance in the latter form

TABLE 2. *The infrared spectra of* 2- *and* 4-*aminopyrimidine and their* N-*methyl derivatives in the* N–H *stretching,* N–H *deformation, and double-bond stretching regions.*

	N–H stretching frequencies (cm.$^{-1}$)			Double-bond stretching and N–H deformation frequencies (cm.$^{-1}$)
	Free	Associated		
Pyrimidine derivative	In solution	In solution	In the solid	In the solid
2-Amino	3545 sh	3314 b	3327 b	1650 s, 1577 s
	3430 sh	3172 b	3166 b	
Same deuterated	2655 sh	2493 b	2523 b	1596 s
	2573 sh	2400 b	2395 b	
2-Methylamino	3463 sh	3280 b	3268 b	1617 s
Same deuterated	2565 sh	2416 b	2420 b	1617 s
1 : 2-Dihydro-2-imino-1-methyl	3324 sh	—	3244 b	1638 s,
Same deuterated	2455 sh	—	—	1638 s,
1 : 2-Dihydro-2-imino-1-methyl, hydriodide	—	—	3262 b	1645 s,
			3085 b	
Same deuterated	—	—	2498 b	1646 s,
			2411 b	
4-Amino	3538 sh	3322 b	3324 b	1652 s, 1594 s
	3424 sh	3180 b	3178 b	
Same deuterated	2640 sh	2498 b	2496 b	1601 s
	2561 sh	2401 b	2399 b	
4-Methylamino	3466 sh	3264 b	3245 b	1614 s
	3443 sh			
Same deuterated	2570 sh	2428 b	2445 b	1616 s
	2555 sh			
1 : 4-Dihydro-4-imino-1-methyl, hydriodide *	—	—	3260 b	1648 s
			3109 b	
Same deuterated	—	—	2500 b	1646 s
			2410 b	

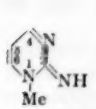
* The free imine could not be isolated.
sh = sharp, b = broad, s = strong.

which prevents full coplanarity between the nucleus and the methylamino-group. It is unlikely that the doublet arises from amine–imine tutomerism, as 1 : 2-dihydro-2-imino-1-methylpyrimidine (the 4-isomer cannot be isolated from its salts without decomposition) absorbs at 3324 cm.$^{-1}$ in dilute solution and at 3244 cm.$^{-1}$ in the solid state.

In the double-bond stretching region, which includes the range of the N–H deformation mode, 2- and 4-aminopyrimidine show a strong band at 1650 cm.$^{-1}$ which is due to the internal deformation of the amino-group, for it disappears upon deuteration. In the same region, the salts of 1 : 2-dihydro-2- and 1 : 4-dihydro-4-amino-1-methylpyrimidine absorb strongly at 1646 cm.$^{-1}$ and the deuterated compounds show the same absorption, which is probably due therefore to the C=N stretching mode. 2- and 4-Methylaminopyrimidine give rise to a strong band near 1615 cm.$^{-1}$, but no perceptible band at higher frequencies in the N–H deformation mode and double-bond stretching mode region. This band is probably due to a ring stretching vibration, since it is unaffected by deuteration, and many other pyrimidine derivatives absorb near this band (Brownlie, *J.*, 1950, 3062; Short and Thompson, *J.*, 1952, 168). Such observations support the view that 2- and 4-amino-pyrimidine exist largely in the true amino-form since the deformation vibration of the primary amino-group generally absorbs strongly, whilst that of the secondary amino-group shows very weak absorption (Bellamy, " The Infrared Spectra of Complex Molecules," London, 1954, pp. 212 ff.).

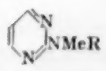
Preparations.—Prolonged action of methyl iodide at 20° on 2-aminopyrimidine gave the hydriodide of 1 : 2-dihydro-2-imino-1-methylpyrimidine (I) which was converted into the

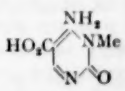
free base (at 0°). In warm alkaline solution, this rapidly rearranged to 2-methylaminopyrimidine (IV) identical with material made from 2-chloropyrimidine and methylamine (Part I, *loc. cit.*). Such rearrangement has recently been described by Carrington, Curd, and Richardson (*J.*, **1955**, 1858) and others have been noticed under different conditions,


(I)

(II)

(III)


(IV; R = H)
(IV*a*; R = Me)


(V)

(VI)

e.g., during the pyrolyticdecarboxylation of 5-carboxy-3-methylcytosine (V) to 2-hydroxy-4-methylaminopyrimidine (VI) (Brown, *J. Appl. Chem.*, 1955, 358) and during nitration of 1 : 2-dihydro-2-imino-1-methylpyridine to give 2-methylamino-5-nitropyridine (Tschitschibabin and Konowalowa, *Ber.*, 1925, **58**, 1712; Tschitschibabin and Kirssanow, *ibid.*, 1928, **61**, 1223). The present rearrangement clarifies the mechanism of the methylation of 2-aminopyrimidine: Overberger and Kogon (*J. Amer. Chem. Soc.*, 1954, **76**, 1065) describe a hydriodide of m. p. 241—242°, from which 2-methylaminopyrimidine was obtained by warm alcoholic alkali; this intermediate corresponds in m. p. and other properties with 1 : 2-dihydro-2-imino-1-methylpyrimidine hydriodide, and rearrangement followed during the alkaline treatment.

When 4-aminopyrimidine is methylated similarly, two products, 1 : 4-dihydro-4- and 1 : 6-dihydro-6-imino-1-methylpyrimidine (II and III), are possible, but a single 4-imino-derivative resulted. In this case the free base was very unstable: the picrate was however made. In alkaline solution no 4-methylaminopyrimidine was formed but hydrolysis occurred to 1 : 4-dihydro-1-methyl-4-oxopyrimidine. This proved the structure of the imino-derivative. An attempt to prepare 1 : 2 : 3 : 4-tetrahydro-2 : 4-di-imino-1 : 3-dimethylpyrimidine gave only a single monomethylated derivative of indeterminate structure.

Experimental

Analyses were done by Mr. P. R. W. Baker, Beckenham.

Spectra.—Ultraviolet absorption spectra were measured with a Hilger Uvispek H700/301 Quartz Spectrophotometer, on buffer solutions with the pH values recorded in Table 1. The solvents were 0·01M-phosphate (pH 7) and 0·1N-potassium hydroxide (pH 13).

Infrared absorption spectra were measured with a Perkin-Elmer Model 12C recording spectrometer, and lithium fluoride and sodium chloride prisms. The compounds listed in Table 2 were examined in CCl_4 solution over the approximate concentration range 0·01—0·2M in cells of 1 and 10 mm. path length, and the spectra of the solids were obtained with samples of the compounds compressed into discs with potassium bromide.

1 : 2-*Dihydro*-2-*imino*-1-*methylpyrimidine Hydriodide.*—2-Aminopyrimidine (5·0 g.), methyl iodide (10 ml.), and methanol (60 ml.) were kept for 5 days at room temperature. The precipitated hydriodide was collected (8·1 g.; m. p. 242—244°), and the filtrate stored 10 days more to obtain additional product (2·9 g.) (total yield 88%). Recrystallization from 95% ethanol (35 parts) gave thick colourless prisms of 1 : 2-*dihydro*-2-*imino*-1-*methylpyrimidine hydriodide*, m. p. 247—248° (decomp.) (Found: N, 17·75; I, 54·0. $C_5H_8N_2I$ requires N, 17·75; I, 53·55%).

1 : 2-*Dihydro*-2-*imino*-1-*methylpyrimidine.*—The hydriodide (0·23 g.), cooled at 0°, was moistened with water (2 drops), covered with purified ether (10 ml.), and then ground thoroughly (glass rod) with powdered potassium hydroxide (1 g.) added in several small portions. The ether, which became yellow, was separated by decantation. The residue was washed with ether (3 × 5 ml.). The combined ether extracts were dried (Na_2SO_4) and most of the ether was distilled off, leaving yellow crystals (about 0·1 g.) from which mother-liquor was removed by means of a filter stick to minimize exposure to the atmosphere. Recrystallization was carried out by redissolution in ether, drying (KOH), filtration through a cotton plug, concentration until crystallization began, cooling to room temperature, and filtration with a filter stick. The last traces of ether and moisture were removed by storage (2 hr.) in a desiccator ($CaCl_2$;

100 mm.), leaving very hygroscopic, thick yellow needles of 1 : 2-*dihydro*-2-*imino*-1-*methylpyrimidine*, m. p. 102—104° (Found : C, 54·95; H, 6·45; N, 38·45. $C_5H_7N_3$ requires C, 55·05; H, 6·5; N, 38·5%.)

The *picrate* was prepared from the hydriodide (0·22 g.), picric acid (0·21 g.), and water (5 ml.). Recrystallization from ethanol (20 parts) gave yellow granules, m. p. 198—200° (Found : N, 24·95. $C_{11}H_{10}O_7N_6$ requires N, 24·85%), identical (mixed m. p.) with the picrate prepared from the free base.

2-*Methylaminopyrimidine* (*by Rearrangement*).—A solution of 1 : 2-dihydro-2-imino-1-methylpyrimidine hydriodide (1·0 g.) in aqueous N-sodium hydroxide (12 ml.) was heated on a steam-bath for 10 min., then cooled and extracted with chloroform (2 × 10 ml.). Evaporation and recrystallization of the residue from light petroleum (b. p. 60—80°; 10 parts) gave 71% of 2-methylaminopyrimidine, m. p. 59—60° (Found : C, 54·95; H, 6·45; N, 38·8. Calc. for $C_5H_7N_3$: C, 55·05; H, 6·5; N, 38·5%). The m. p. was undepressed by authentic material (Part I).

The picrate, recrystallised from methanol (70 parts), had m. p. 191° (Overberger and Kogon, *loc. cit.*, give 195—196°) (Found : N, 25·0. Calc. for $C_{11}H_{10}O_7N_6$: N, 24·85%). A mixed m. p. with 1 : 2-dihydro-2-imino-1-methylpyrimidine picrate showed depression but there was none with authentic 2-methylaminopyrimidine picrate.

1 : 4-*Dihydro*-4-*imino*-1-*methylpyrimidine Hydriodide*.—4-Aminopyrimidine (5·0 g.), methyl iodide (5 ml.), and methanol (25 ml.) were refluxed for 1 hr. The precipitate which formed upon cooling (10·0 g., 80%; m. p. 204—205°), recrystallised from ethanol (20 parts), gave 1 : 4-*dihydro*-4-*imino*-1-*methylpyrimidine hydriodide*, m. p. 205—206° (Found : N, 17·75; I, 53·35. $C_5H_8N_3I$ requires N, 17·75; I, 53·55%). In another preparation the reactants were set aside for three days at room temperature. A different crystalline form of the hydriodide was at first obtained, having m. p. 163—164°. Recrystallization from ethanol (20 parts) or storage for 3 days gave the other form, m. p. 205—206°.

The *picrate* was prepared from the hydriodide (0·24 g.), picric acid (0·23 g.), water (10 ml.), and N-sodium hydroxide (1 ml.). Recrystallization from ethanol (100 parts) gave yellow needles, m. p. 172—173° (Found : N, 24·8. $C_{11}H_{10}O_7N_6$ requires N, 24·85%).

Hydrolysis of 1 : 4-*Dihydro*-4-*imino*-1-*methylpyrimidine*.—The hydriodide (0·9 g.) and 0·1N-sodium hydroxide (80 ml.) were set aside for 10 hr. at 20—25°. The solution was brought to pH 5 with hydrochloric acid and evaporated to dryness *in vacuo*, moistened with a little benzene, and re-evaporated. The residue was dissolved in ethanol, filtered from salt, and added to saturated alcoholic picric acid (20 ml.). The precipitate (55%) was recrystallised from ethanol (90 parts), giving a yellow solid, m. p. 164—166°.

1 : 4-*Dihydro*-1-*methyl*-4-*oxopyrimidine picrate* made from authentic base (Part II, *loc. cit.*) also had m. p. 164—166° (Found : N, 20·4. $C_{11}H_9O_8N_5$ requires N, 20·65%). The two specimens showed no mixed m. p. depression, but each depressed the m. p. of 1 : 6-dihydro-1-methyl-6-oxopyrimidine picrate (Part II, *loc. cit.*).

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The Evidence of Conductivity, Density, and Viscosity on the Reaction of Nitryl Fluoride with Sulphuric Acid. The Conductivity of Solutions of Nitryl Fluoride in Selenic and Phosphoric Acids.

By G. Hetherington, D. R. Hub, and P. L. Robinson.

[Reprint Order No. 6359.]

Nitryl fluoride, in concentrations up to 68 mol.%, reacts exothermally and irreversibly with sulphuric acid to give clear colourless liquids; at 70 mol.% colourless crystals separate and the mother-liquor immediately becomes yellow. Electrical conductivities, densities, viscosities, and Raman spectra of the solutions have been used to interpret the chemistry of the system.

In selenic acid nitryl fluoride behaves similarly and also, at a sufficient concentration, gives colourless crystals. The conductivities of this system have been measured.

In phosphoric acid a different form of conductivity curve is obtained and the chemistry is not the same.

Sulphuric Acid

Nitryl fluoride boils at −73° to give a colourless vapour which is readily absorbed by concentrated sulphuric acid with the liberation of much heat. Provided the reactants are kept at laboratory temperature during the mixing, there is evidence, up to 68 mol.%, that very little of the nitryl fluoride dissociates to nitrogen peroxide and fluorine. The vapour is so quickly absorbed that bubbles rarely break the surface; more than 2 moles per mole can be taken up. At about 70 mol.%, when the volume of liquid has increased roughly two and a half times, colourless crystals separate and the mother-liquor is coloured yellow by nitrogen peroxide. Analyses suggest the solid is nitronium hydrogen sulphate, NO_2HSO_4, but this needs confirmation and work to that end is in progress.

Let us state what we think happens in the course of absorption up to the separation of the solid and then present the evidence and argument upon which our opinions are based. But first it is emphasised that the reaction differs from that of dinitrogen tetroxide with sulphuric acid by being irreversible and attended by a greater energy change.

The cryoscopic and molar conductivity data applicable to solutions up to 1·0 mol.% indicate respectively *five* particles and *two* ions of high mobility within this concentration limit. These requirements are met by the irreversible reaction (1), followed by the reversible reaction (2):

$$NO_2F + H_2SO_4 \longrightarrow NO_2^+ + HF + HSO_4^- \quad . . . . . (1)$$

$$HF + 2H_2SO_4 \rightleftharpoons H_3O^+ + HSO_3F + HSO_4^- \quad . . . . . (2)$$

Lange's work (*Z. anorg. Chem.*, **1933**, **215**, 321) implies that the equilibrium of (2) is well to the right in the absence of moisture so that when combined with (1) it gives the *five* particles and *two* major conducting ions required. Moisture, according to Lange (*loc. cit.*), caused (2) to move from right to left and this may be the reason for the absence of Raman evidence for fluorosulphonic acid in the more concentrated solutions of nitryl fluoride, though it is possible that the lines are masked. Without more knowledge of the hydrogen fluoride–sulphuric acid system, the authors feel it safer to assume that at higher concentrations much of the hydrogen fluoride remains as such. With these premises, the dissolution of nitryl fluoride in sulphuric acid may be conveniently referred to six stages.

Stage I, to 1·0 mol.%, the irreversible reaction (1), followed by the equilibrium (2).

Stage II, from 1·0 to 9·6 mol.%, the irreversible reaction (1), accompanied by the reversible reaction producing nitronium hydrogen sulphate in solution

$$NO_2^+ + HSO_4^- \rightleftharpoons NO_2HSO_4 \quad . . . . . (3)$$

Stage III, at about 22 mol.%, the concentration of maximum viscosity, where the increase in viscosity due to NO_2HSO_4 is counterbalanced by the dilution effect of HF.

Stage IV, at 50 mol.%, near the concentration of minimum conductivity (47 mol.%), where all the H_2SO_4 has been used in reaction (1).

Stage V, from 50 to 68 mol.%, the conductivity rises, NO_2F continues to dissolve in the liquid forming more NO_2^+, possibly by reacting with HSO_4^- ions:

$$NO_2F + HSO_4^- \longrightarrow NO_2^+ + HF + SO_4^= \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Stage VI, at 70 mol.%, the liquid is saturated with NO_2HSO_4 and crystals (possibly of this composition) separate. Nitrogen peroxide turns the mother-liquor yellow. If the relative absence of secondary reactions is assumed, the molar ratio of species present immediately before the formation of solid should be approximately.

$$NO_2^+ : HF : HSO_4^- : SO_4^= = 3 : 3 : 1 : 1$$

The removal of some HSO_4^- ions by the solid prevents reaction (4) and allows NO_2F to accumulate which can then decompose:

$$2NO_2F \longrightarrow N_2O_4 + F_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

The addition of H_2SO_4 causes the solid to dissolve and the colour disappears because of the reaction

$$N_2O_4 + 3H_2SO_4 \rightleftharpoons NO_2^+ + NO^+ + H_3O^+ + 3HSO_4^- \quad . \quad . \quad . \quad . \quad (6)$$

Electrical Conductivity.—This rises to a maximum with 9·6 mol.% [see Fig. 1 (*a*)], falls to a minimum with 47 mol.%, and then rises again until, at 70 mol.%, the separation of solid prevents further measurement. These changes are to be considered in relation to molar conductivity and cryoscopic measurements in solutions up to 0·5M, to densities of solutions up to 22 mol.%, to viscosities up to 44 mol.%, and to Raman spectra at 15·6 and 23·1 mol.%. The hydrogen fluoride present slowly attacks glass, and more slowly silica, releasing bubbles of silicon tetrafluoride at the surfaces. These, though troublesome in all work at high concentrations, and for spectral observation even at intermediate concentrations, do not prevent a fair degree of accuracy in other measurements.

No previous conductivity measurements have been made on these solutions, and those made on dilute solutions of sulphuric acid in hydrogen fluoride (Fredenhagen and Cadenbach, *Z. phys. Chem.*, 1930, **146**, 245; Fredenhagen, *Z. anorg. Chem.*, 1939, **242**, 23) and interpreted as indicating ionisation of the following kind

$$H_2SO_4 + 2HF \longrightarrow HSO_3F + H_3O^+ + F^-$$

have little bearing on the present work. We have passed fluorine through a solution of dinitrogen tetroxide only to find a negligible amount of it absorbed and little effect on the conductivity. This confirmed us in our rejection of the idea of appreciable decomposition of nitryl fluoride by reaction (5) in these solutions below 70 mol.%, which had been previously made on the grounds that no fluorine is disengaged.

TABLE 1. *Molar conductivities of dilute solutions at 25°.*

Concn. (mole $l.^{-1}$)	NO_2F	Mono-(HSO_4^-) H_2O	Di-(HSO_4^-) HNO_3	Tri-(HSO_4^-) N_2O_4	Tetra-(HSO_4^-) hexamethylenetetramine
0·05	362	—	306	—	454
0·10	225	156	229	296	349
0·15	214	—	197	—	—
0·20	191	115	177	—	—
0·30	161	100	155	—	—
0·40	141	90	138	—	—
0·50	125	—	125	—	—

Molar Conductivities.—Table 1 allows our molar conductivities of nitryl fluoride solutions in sulphuric acid to be compared with those of mono-, di-, tri-, and tetra-hydrogen sulphate ionising compounds (see Gillespie and Wasif, *J.*, 1953, 221). Clearly from this the irreversible reaction with sulphuric acid, at least up to a concentration of 0·5M, belongs to the

di-hydrogen sulphate class and should be represented by equations (1) and (2), rather than by (1) alone.

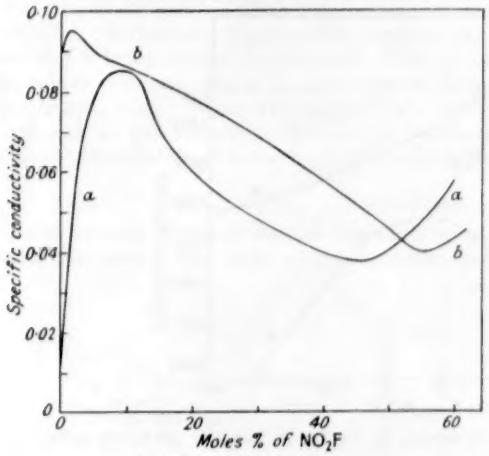
Cryoscopic Evidence.—Equations (1) and (2) imply the formation of five osmotic particles per molecule of solute and their presence is confirmed by the depression of the freezing point of nitryl fluoride in 100% sulphuric acid [Fig. 2 (*b*)] in relation to those of nitric acid (*a*) and dinitrogen tetroxide (*c*) in the same medium, which produce, respectively, four and six particles per molecule of solute :

$$HNO_3 + 2H_2SO_4 \rightleftharpoons NO_2^+ + H_3O^+ + 2HSO_4^-$$

$$N_2O_4 + 3H_2SO_4 \rightleftharpoons NO_2^+ + NO^+ + H_3O^+ + 3HSO_4^-$$

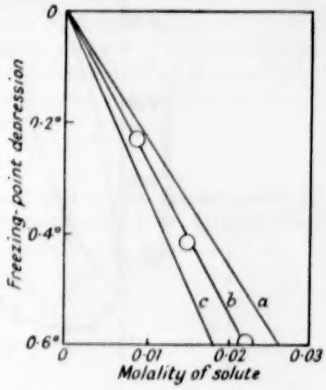
At higher concentrations, following our premise that there is not much fluorosulphonic acid, the main reaction would appear to be (1) which is held to account for the hydrogen sulphate ions; these mainly give rise to the conductivity which has its maximum at 9·6 mol.%.

FIG. 1. *Specific conductivities of solutions of nitryl fluoride in sulphuric and selenic acid.*



(*a*) H_2SO_4, (*b*) H_2SeO_4.

FIG. 2. *Cryoscopic data for nitric acid, nitryl fluoride, and dinitrogen tetroxide in sulphuric acid.*



(*a*) HNO_3, (*b*) NO_2F, (*c*) N_2O_4.

At 50 mol.%, where the conductivity is near a minimum, all the sulphuric acid has been used by reaction (1), and, as the reaction is irreversible, the only species certainly present in quantity are molecular hydrogen fluoride and nitronium hydrogen sulphate, and the ions NO_2^+ and HSO_4^-.

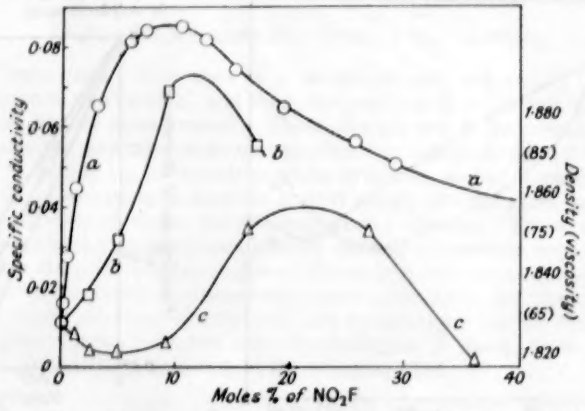
Densities.—These [Fig. 3(*b*)] rise to a maximum at about 11 mol.% and then fall with increasing concentration. In spite of the maximum's occurring at a composition near that giving the greatest conductivity [Fig. 3(*a*)] and of a parallelism between the two curves, we believe there is little connection between density and conductivity. As with dinitrogen tetroxide (see Hetherington, Nichols, and Robinson, *J.*, 1955, 3141,) the increase in density is ascribed to solvation of the nitronium ion, and the subsequent decrease to dilution. For nitryl fluoride the dilution effect comes earlier because all the diluent, hydrogen fluoride, remains intact; whereas of the nitrogen peroxide added, some reacts, even up to a high concentration, with the sulphuric acid.

Viscosities.—On the other hand the viscosities (again as with dinitrogen tetroxide), seem to be closely associated with the conductivities and, up to a concentration of 47 mol.% largely to control them. The curve, Fig. 3(*c*), falls to a minimum at a concentration just a little below that responsible for the maximum conductivity and rises steeply after that point is passed. By the reasoning adopted in the case of dinitrogen tetroxide, the initial

fall in viscosity is ascribed to the formation of the nitronium ion and the subsequent rise to compound formation; then the compound was nitrosonium hydrogen sulphate, now it is probably nitronium hydrogen sulphate. The second decline in viscosity is due to dilution with hydrogen fluoride which, when this decline becomes apparent, is present to the extent of about 22 mol.%.

The final rise in conductivity from about 47 mol.% must be related to the fact that at 50 mol.%, although all the sulphuric acid has been used, nitryl fluoride continues to be freely absorbed. Some of it must go to increase the concentration of nitronium ion if, as we believe, a nitronium salt eventually comes out of solution. This increase may be caused by the nitryl fluoride's reacting with the hydrogen sulphate ion according to equation (4). Such a reaction would at once account for the increase in conductivity observed by allowing the substitution of a $SO_4^{=}$ for a HSO_4^{-} ion, and for the rise in concentration of the nitronium ion which forces precipitation. That nitrogen peroxide appears in the solution immediately the solid begins to separate betokens a decomposition of the sort shown in (5). This may be brought about by a dearth of HSO_4^{-} ions with which the additional nitryl fluoride can

FIG. 3. *Conductivities, densities, and viscosities of solutions of nitryl fluoride in sulphuric acid.*



(*a*) Specific conductivity (ohm^{-1} cm.$^{-1}$); (*b*) density (g. c.c.$^{-1}$); (*c*) viscosity (arbitrary units).

react (4), or may be due to the formation of a soluble molecular compound between nitryl fluoride and the nitronium salt at high concentrations, which leads to the release of the former when the latter is precipitated. Either need occur only to a slight degree to account for the phenomena observed.

Raman Spectra.—Through the courtesy of Dr. F. M. Brewer, we prepared nitryl fluoride and two solutions of it in sulphuric acid in the Inorganic Chemistry Laboratory, Oxford, where Dr. L. A. Woodward and Mr. J. A. Rolfe kindly examined their Raman spectra. The results obtained for nitryl fluoride itself will be published shortly. The concentrations of the two solutions were 15·6 and 23·1 mol.%, the first a little beyond the conductivity maximum and the second near the viscosity maximum. Neither showed any sign of the spectrum of nitryl fluoride. This is in harmony with the view that its reaction with sulphuric acid is not reversible—Ruff, Menzel, and Neumann (*Z. anorg. Chem.*, 1932, **208**, 293) found the reaction of nitrosyl fluoride with sulphuric acid to be irreversible. Nor were any Raman lines observed which could be attributed to fluorosulphonic acid or the fluorosulphonate ion. Apart from slight shifts of the frequencies of the solvent the only characteristic features shown by the solutions were the frequencies 1034, 1397, and 2290 cm.$^{-1}$. There is little doubt that the first of these is due to HSO_4^{-} and the second to the nitronium ion NO_2^{+} (cf. Ingold, Millen, and Poole, *J.*, 1950, 2576), and the presence of these ions is completely in keeping with the picture of the system given above. The third

frequency, 2290 cm.$^{-1}$, is close to that of the nitrosonium ion NO^+ (Millen, *J.*, 1950, 2600) to which it presumably must be ascribed. This evidence for the presence of nitrosonium ions in appreciable concentration in these solutions is surprising unless it happens to be due to the fact that they were prepared by diluting solutions of or near 63·5 mol.% with sulphuric acid. At this concentration the decomposition (5) could operate and, once formed, the nitrosonium ions would remain in the liquid. In sulphuric acid solutions of dinitrogen tetroxide, where nitrosonium and nitronium ions occur in equal concentrations, only a nitrosonium salt is precipitated. With nitryl fluoride we have found no sign of nitrosonium salt in the solid and this would indicate that the concentration of the ion in these solutions is probably not high.

Selenic Acid

Selenic acid absorbs more than 2 moles of nitryl fluoride per mole of selenic acid. The conductivities of the solutions are shown in Fig. 1(*b*). There is some doubt about the value for the acid itself, which may be much lower than we found (see below). The curve, except for its initial portion, resembles that of the sulphuric acid solutions and the phenomena displayed are the same, including the absence of colour up to 68 mol.% and the separation of a solid at 70 mol.% followed by an immediate colouring of the solution with nitrogen peroxide. Preliminary examination suggests the solid is nitronium hydrogen selenate, and this is being further investigated. The evidence points to a series of stages as nitryl fluoride is absorbed, similar in most respects to those already postulated for the solutions in sulphuric acid. Where the stages differ is in the concentrations at which the maximum (1·40 mol.%) and minimum (58·6 mol.%) conductivities are found. Equations (1) to (5), with the substitution of Se for S are applicable to this system.

Phosphoric Acid

The amount of nitryl fluoride absorbed by phosphoric acid is also considerable, 1·7 moles per mole. The curve of conductivities against concentration (Fig. 4) is however

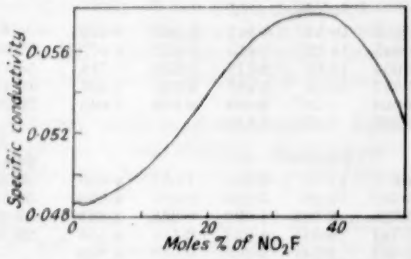


Fig. 4. *Specific conductivities of solutions of nitryl fluoride in phosphoric acid.*

entirely different as, indeed, are the phenomena observed. But even in this case there is a small initial maximum at 1 mol.% at which point the solution becomes coloured with nitrogen peroxide. Beyond this the curve slowly rises to a second very blunt maximum and, at a concentration of approximately 60 mol.%, a colourless solid begins to separate. Neither the solid nor the system has been fully investigated.

Experimental

Materials.—Sulphuric acid of minimum conductivity at 25·00 ± 0·01° was prepared in the manner described by Hetherington, Hub, Nichols, and Robinson (*J.*, 1955, 3300), using a cell similar to that of Gillespie and Wasif (*J.*, 1953, 204) but with its electrode chamber disposed vertically instead of horizontally. Electrical measurements were to ±0·00002 ohm^{-1} cm.$^{-1}$.

As supplied in sealed ampoules (B.D.H. pure) selenic acid is extremely hygroscopic and its conductivity is markedly increased by the slighest exposure to the atmosphere. Although the individual specimens varied little in specific conductivity the figure found, 0·09105 ohm^{-1} cm.$^{-1}$ at 25°, is probably high; that for the absolute acid might be expected to be more of the order of the 0·01045 ohm^{-1} cm.$^{-1}$ recorded for sulphuric acid.

Also from ampoules (B.D.H. 100%), phosphoric acid was used as supplied, and again our

figure 0·04858 ohm^{-1} cm.$^{-1}$ could be high. Since with selenic and phosphoric acid we were more interested in the form of the conductivity curves of the nitryl fluoride solutions than in the accuracy of particular points, we contented ourselves with these materials.

Nitryl fluoride, prepared and purified by the method developed in this laboratory (*J.*, **1954**, 1119), was kept in the Pyrex break-seal vessels as short a time as possible before use.

The fluorine for saturation of the dinitrogen tetroxide and nitryl fluoride solutions in sulphuric acid was prepared electrolytically and purified by passage over dry sodium fluoride and through a trap cooled to −180°.

Manipulation and Measurement.—The solutions were prepared in an all-Pyrex glass apparatus at 0° and transferred to the conductivity cell without contact with the air of the room. The cell was similar in design to the small one used by Gillespie and Wasif (*J.*, **1953**, **204**). As it was constructed of Pyrex glass, the stout electrode leads were fitted snugly into vertical tubes and the joints rendered vacuum-tight by a lining and capping of " Polythene." The cell provided for a resistance greater than 1000 ohms, and its constants were determined by the use of potassium chloride solutions of accurately known strength, the specific conductivities of Jones and Bradshaw (*J. Amer. Chem. Soc.*, **1933**, **55**, 1780) for these solutions being employed. The temperature of the liquids during measurements was kept at 25·00° ± 0·01° by means of a thermostat. Only at high concentrations of nitryl fluoride was difficulty experienced from the formation of bubbles of silicon tetrafluoride and this could be overcome by tilting the cell just before making the final adjustment and allowing the bubbles to escape from the electrode chamber into the upper part of the cell. The circuit used for measuring the resistances will be described in detail later.

The densities were determined by weighing a known volume of liquid under conditions which protected it from atmospheric moisture. The viscosities, being for comparison only, are in arbitrary units. The range of composition over which these two properties could be measured was limited by the appearance of gaseous silicon tetrafluoride beyond a certain concentration.

The specific conductivities of nitryl fluoride in the three solvents at 25·00°, κ (ohm^{-1} cm.$^{-1}$), are set out below :

Mol.%	100κ	Mol.%	100κ	Mol.%	100κ	Mol.%	100κ	Mol.%	100κ	Mol.%	100κ
		Sulphuric acid.						*Selenic acid.*			
63·69	5·619	19·34	6·442	3·046	6·496		*Expt.* 1.				
58·26	4·643	15·22	7·413	1·412	4·447	67·84	4·204	30·17	6·694	9·402	8·703
50·08	3·904	12·66	8·175	0·626	2·714	56·73	4·029	18·81	7·830	4·463	8·972
44·29	3·895	10·56	8·497	0·240	1·586	46·48	5·089	13·48	8·470	0·000	9·105
29·20	5·064	7·287	8·408	0·000	1·045	39·08	5·920				
25·73	5·569	6·026	8·148				*Expt.* 2.				
		Phosphoric acid.				64·44	4·635	18·68	7·827	0·922	9·542
57·54	4·621	15·73	5·227	1·032	4·860	56·85	4·378	11·33	8·492	0·478	9·479
39·36	5·762	12·09	5·094	0·550	4·856	50·62	4·814	5·481	8·949	0·202	9·429
34·35	5·766	8·823	4·992	0·255	4·863	39·29	6·194	2·661	9·405	0·000	9·105
30·75	5·741	6·045	4·927	0·119	4·858	29·70	6·900	1·675	9·492		
25·00	5·597	3·581	4·886	0·052	4·858						
20·30	5·394	1·983	4·869	0·000	4·858		*Expt.* 3.				
						19·36	8·015	4·340	8·969	0·795	9·490
						8·282	8·709	1·626	9·535	0·000	9·105

The effect on the specific conductivity of dinitrogen tetroxide solutions in sulphuric acid of passing through them appreciable quantities of fluorine is evidently small (see Table).

N_2O_4, mole%	42·66	20·24	6·11	2·08
100κ (ohm^{-1} cm.$^{-1}$), before passing F_2	3·25	7·25	10·15	7·22
after "	3·36	6·88	10·34	7·16
Fluorine passed (g.)	2·0	2·0	5·2	2·0

The authors thank Dr. Brewer, Dr. Woodward, and Mr. Rolfe for the help indicated, and Imperial Chemical Industries Limited, General Chemicals Division, Widnes, for the use of the fluorine cell. This work was carried out during the tenure of a Salters' Fellowship (G. H.) and a D.S.I.R. maintenance grant (D. R. H.).

King's College, Newcastle-upon-Tyne, 1. [*Received, April 27th*, 1955.]

The Fractionation of Normal and Mottled Wheat Starch by Elution in the Absence of Oxygen. Viscometric Properties of the Amylose Fraction.

By H. Baum, G. A. Gilbert, and H. L. Wood.

[Reprint Order No. 6541.]

Wheat starch is shown to be extracted easily in high yield from grains which have been softened without chemical treatment by 2 minutes' heating in water. Undried starch, freshly prepared in this way, is dispersed in water at 95° for 10 min. in a stream of nitrogen which, besides excluding oxygen, stirs the suspension and generates foam which removes surface-active impurities. Centrifugation of the cooled dispersion leads to a fractionation of the starch into *ca.* 25% by weight of amylose of " blue value " 1·1—1·2 and 75% by weight of amylopectin of " blue value " 0·15. The intrinsic viscosity of the acetylated amylose in chloroform solution at 20° is found to be 4·8. There appears to be no difference between the properties of normal and mottled wheat starch.

Two principal methods are available for the fractionation of starch. In the first to be discovered (A) the starch is extracted for a few moments with hot water which elutes amylose from the granules and leaves amylopectin as an undissolved gel. In the other method (B) the starch is heated in water or autoclaved until it appears to be completely dissolved, and then a selective precipitant is added which forms an insoluble complex with the amylose and leaves the amylopectin in solution. These methods are reviewed in detail by Schoch (in Radley, " Starch and its Derivatives," Chapman and Hall, London, 1953, Vol. I, p. 123). Method (A) has had a long history. Its use is described by Maquenne (*Compt. rend.*, 1908, **146**, 542) in observations on a note by Gatin-Gruzewska (*ibid.*, 1908, **146**, 540) concerning the fractionaction of alkali-dispersed starch. Maquenne boiled potato starch in various salt solutions and separated the dissolved amylose from the residual amylopectin by filtration. Since as much as 60% of the granule was dissolved and so assessed as amylose, only a very poor fractionation could have been achieved. Improved results were obtained by Tanret (*ibid.*, 1914, **158**, 1353) by restricting the time of extraction to a few moments, 73% of potato starch then remaining undissolved, compared with 40% if extraction was continued for an hour.

Schoch (*op. cit.*, p. 136) has concluded that methods of fractionation depending upon leaching fail to be efficient owing to the concurrent leaching of amylopectin, and to retrogradation within the granule of approximately half the amylose which thereby becomes included in the amylopectin fraction.

Method (B), discovered by Schoch (*Cereal Chem.*, 1941, **18**, 121) and independently by Weigel (*Z. phys. Chem.*, 1941, **188**, *A*, 137), requires both fractions to be dissolved. Vigorous stirring of the dispersion for several hours at 92° is said to achieve this for cereal starches (Schoch, *op. cit.*, p. 146). Higginbotham and Morrison (*Shirley Inst. Mem.*, 1948, **22**, 148) find that potato starch requires 1—2 days at 90° with moderately vigorous stirring. Addition of butanol or pentanol to such dispersions leads on cooling to the precipitation of amylose as a complex, and a practically complete separation from amylopectin is attained after one or two repetitions of the process.

Clearly one essential difference between the two methods is the state of subdivision of the amylopectin, and the question has to be asked whether the amylopectin becomes dissolved owing to degradation or to disaggregation.

Oxygen causes the slow degradation of amylose in hot neutral solution (Bottle, Gilbert, Greenwood, and Saad, *Chem. and Ind.*, 1953, 541), and may be assumed to do the same to amylopectin. After this had been noted, an attempt was made to prepare undegraded fractions of potato starch by method (B) using rigorously oxygen-free conditions of dispersion (Baum and Gilbert, *ibid.*, 1954, pp. 489, 490). The attempt failed because treatment at 100° for several hours did not dissolve any of the amylopectin. This, however, provided ideal conditions for the application of method (A), since amylose dissolved

immediately. Centrifugation in the presence of sodium chloride led to fractionation comparable in effectiveness with method (B), giving amylose of "blue value" 1·2—1·3 and amylopectin of "blue value" 0·2. The improvement in efficiency of method (A) compared with the earlier work criticised by Schoch cannot be attributed to the use of anaerobic conditions alone. Of equal importance may have been the use of undried freshly prepared starch and the absence of mechanical stirring. The part played by each of these factors and the effects of variety of potato and season are under investigation. Starches from different botanical sources are also being studied, and this paper describes the application of the method to wheat starch.

Ripe wheat sometimes shows a defect in the grain which has led to the term "mottled wheat" because some or all of the grains in an ear are then relatively soft, opaque, and paler yellow than the normal hard and translucent grains. The work of one of us (H. L. W., in the press) had shown that there were significant differences between mottled and normal wheat grains in nitrogen and moisture content and in ash composition, and advantage was taken of the present investigation to compare the starch of the two forms. Only one variety of wheat was examined, namely "Charter" from Queensland, Australia, harvested in November, 1953.

Experimental

Isolation of the Starch from the Grain.—It is necessary to soften the grain before starch can be extracted efficiently, but any chemical treatment which might degrade the starch has to be avoided. It was found sufficient to heat the wet grain for 2 min. in a boiling-water bath. Simultaneously the enzyme activity of the grain was reduced or destroyed. For the softening process, about 50 g. of washed grain were placed in a container connected to a gas-train (nitrogen or hydrogen purified over hot copper). After evacuation at a water-pump for 10 min. to remove air from the vacuoles, the grain was flooded with air-free water from the previous vessel in the train, and gas passed through the mixture for a further 20 min. A boiling-water bath was then placed round the container for 2 min. with the gas still passing. After being cooled, the grain was removed and washed well with distilled water.

The softened grains were crushed individually by a hammer (rollers could be substituted for larger-scale work) and blended for 3 min. in a high-speed "Atomix" blender containing 1% sodium chloride solution. The blend was poured through muslin to remove husks, bran, and coarse material, and the filtrate centrifuged to sediment the starch. The starch was washed three times in the centrifuge with ice-cold water, this serving also to coagulate the protein accompanying the starch. The starch was removed from the coagulum by gentle swirling of the ice-cold water, followed by filtration through muslin, the process being repeated if necessary. After being allowed to settle, the starch was kept at 0° under water. A high yield of starch was obtained (visual estimate) compared with a very low yield if the initial softening process was omitted.

Dispersion and Fractionation.—Dispersion was carried out in distilled water at approx. 95° in a fast stream of nitrogen, which had the dual purpose of preventing oxidation and of providing stirring without damage to the soft gel particles of amylopectin. The dispersion vessel was made by sealing a length of glass tubing (15 × 4 cm.) to the top of a Grade-3 sintered glass filter-funnel (plate diam. 4 cm.), the stalk of which was turned up to serve as a gas inlet. The vessel was capped by a B45 ground joint which led to a water bubbler to exclude air. Gas was passed first through the empty vessel, and then a slurry of fresh undried starch granules in 100 ml. of water was added (0·5% w/v final concentration of starch) and the gas stream continued in the cold for 30 min. The vessel was then heated in boiling water for 10 min. Frothing began after about 1 min. and continued for about a further 4 min. The foam passed right out of the vessel, carrying with it surface-active materials, and thereby freeing the starch of most of its protein and fatty impurities. The starch dispersion was next cooled to about 30°, removed, and centrifuged. It separated readily into a clear supernatant liquid and a tightly packed gel. The supernatant liquid was centrifuged a second time if any floating gel particles were noticed. It was then filtered (G4 filter).

The gel of amylopectin was washed on the centrifuge with distilled water until the washings gave no colour with iodine, and then redispersed in distilled water at *ca.* 95° for 10 min. as before. It was then cooled, centrifuged, and washed.

The amylose can most simply be recovered from solution by precipitation with butanol. No further fractionation occurs, but the amylose is obtained in a form suitable for storage under butanol-saturated water. In the present experiments a much more elaborate treatment with butanol was undertaken in order to ensure the removal of any residual fatty materials by extraction with hot butanol.

The amylose solution plus butanol (50 ml.) was put back in the dispersion vessel, de-aerated, and then heated in a water-bath to *ca.* 60° until the opalescent solution became clear. The gas speed was next increased until the two layers became completely mixed, in order to extract fatty materials into the butanol phase. After 2 min. the rate of passage of gas was decreased to allow the layers to re-form, the vessel opened, and the hot butanol layer removed by pipette so far as possible. The surface of the amylose solution was washed with a little fresh butanol, which was removed, and the solution was cooled. The whole process was repeated, and then the amylose solution was cooled in the presence of excess of butanol, and the precipitate centrifuged and stored. No iodine-staining material was present in the supernatant solution and therefore no further fractionation was occurring. As a further precaution in the present experiments the above series of extractions with butanol was repeated before characterisation of the amylose.

Characterisation of the Fractions.—In the initial stages of a study of a procedure for fractionation, the most useful properties to follow are the iodine stains of the two fractions and the intrinsic viscosity of the amylose. The iodine stain is a sensitive measure of the degree of separation attained, and the viscosity indicates whether breakdown has been extensive or not.

The fractions were stained under the conditions described by McCready and Hassid (*J. Amer. Chem. Soc.*, **1943**, **65**, 1154) to obtain " blue values " as defined by Bourne, Haworth, Macey, and Peat (*J.*, **1948**, 924). It is usual to regard pure amylose as having a " blue value " of 1·4 and pure amylopectin a value between 0·1 and 0·2. Before estimation of its " blue value," the amylopectin was refluxed twice with 85% methanol for 2 hr., the hot methanol being decanted each time. The centrifuged suspension was then dried to constant weight *in vacuo* in a drier jacketed by chloroform vapour, and a known weight dispersed in 0·5N-sodium hydroxide. For the " blue value " of whole wheat starch, a dispersion of the starch in hot water was extracted three times with hot butanol as described above for amylose, and then the homogeneous suspension consisting of amylose complex and amylopectin was freeze-dried and dried *in vacuo* in a chloroform-drier. Weighed amounts were dispersed in 0·5N-sodium hydroxide, neutralised, and stained with iodine.

The intrinsic viscosity of amylose was determined under four sets of conditions: (*a*) on undried amylose in 0·5N-sodium hydroxide, (*b*) on freeze-dried amylose in 0·5N-sodium hydroxide, (*c*) on acetylated amylose in chloroform, and (*d*) on deacetylated amylose acetate in 0·5N-sodium hydroxide.

Details.—Viscosity measurements were made at 20° in a modified Ubbelohde viscometer (Davis and Elliott, *J. Colloid Sci.*, **1949**, **4**, 313) which allowed dilution *in situ*. No kinetic-energy corrections were necessary.

The sample of amylose stored under butanol–water was centrifuged and drained. A portion of the wet paste was dissolved in N-sodium hydroxide at room temperature and diluted to half this concentration before the measurement of the intrinsic viscosity. To find the concentration of amylose in this solution, the solution was neutralised and stained with iodine in the normal way, and the optical density compared with the known " blue value " of the sample.

Another portion of the paste was dispersed in hot water, butanol added to precipitate the amylose, and the suspension cooled quickly, frozen, and freeze-dried. The resulting powder, which contained about 5% of moisture, was further dried in a chloroform-drier in a vacuum to constant weight. Samples were used for determination of intrinsic viscosity and " blue value " as above.

A third portion of the paste was acetylated by the method of Higginbotham and Morrison (*loc. cit.*). The paste was washed with dry butanol and then dry pyridine. After 24 hours' storage in pyridine the amylose was shaken at room temperature for 24 hr. with a mixture of equal volumes of pyridine and acetic anhydride. After filtering, the solution was run in a fine stream into ice-water, and the precipitated fibre simultaneously spun on to a glass rod. The fibre was washed well with water, and then with dry ethanol, and finally stored in a vacuum-desiccator over solid potassium hydroxide.

Weighed quantities of the acetate were used for measurements of intrinsic viscosity in chloroform and for deacetylation. Deacetylation was carried out by shaking the acetate for 24 hr. at 0° in N-sodium hydroxide. The solution of amylose formed was diluted to 0·5N-sodium hydroxide for its intrinsic-viscosity determination.

The viscosity of the amylopectin was not determined because of the difficulty of dealing with a suspension of particles with a strong tendency to become oriented in the stream-lines and to settle during the measurement.

Control Experiments.—To determine whether granule size influenced the molecular size of the amylose, a suspension of starch granules in water was allowed to settle for 5 min. and then a sample of the smaller granules which had still not settled was obtained from the upper layer and dispersed and fractionated as before. This amylose sample is marked U_6 in Tables 1 and 2.

The influence of butanol on the viscosity of amylose in alkali was found by determining the intrinsic viscosity in 0·5N-sodium hydroxide containing various concentrations of butanol.

A comparison was also made between the intrinsic viscosity of amylose dissolved in the form of its butanol paste in sodium hydroxide, and amylose from which the butanol had first been removed by steam-distillation under nitrogen.

Storage in neutral solution in the presence of salt had been found to reduce the intrinsic viscosity of potato amylose as measured in alkali (Baum and Gilbert, *loc. cit.*). Some samples of amylose were therefore made 1% in sodium chloride and left for a short time before being made alkaline for viscosity determinations.

Results

The results of six independent fractionation experiments are collected in Table 1. The letter M is used to indicate mottled wheat and U normal wheat; *a*, *b*, *c*, and *d* refer to the conditions in which the viscosities were determined (p. 4049).

Table 1.

		Intrinsic viscosity at 20°				
Amylose sample	"Blue value"	Undried amylose in NaOH (*a*)	Dried amylose in NaOH (*b*)	Amylose acetate in $CHCl_3$ (*c*)	Deacetylated in NaOH (*d*)	Ratio (*c*) : (*d*)
M_1	1·17, 1·25 *	2·8	3·6	4·8	3·0	1·6
U_3	1·10	2·5	3·7	4·8	3·0	1·6
U_5	1·22	—	4·3	4·8	3·0	1·6
M_4	1·10	2·5	3·5	—	—	—
M_5	1·18	—	4·5	—	—	—
U_6	1·17, 1·18 *	—	2·9	3·8	2·4	1·6

* "Blue values" determined on solutions of weighed amounts of amylose acetate in NaOH.

The "blue values" of amylopectin of two samples obtained from independent experiments were both 0·15. No protein was detected in the amylose or the amylopectin fraction. Normal and mottled wheat starch had the same "blue value" within experimental error (0·41 and 0·40 respectively).

Apart from the very small amount of amylose which was discarded in the washings of the amylopectin, losses were merely those due to handling and transference, and were small. If the "blue value" for whole starch of 0·41 is combined with that of 0·15 for amylopectin and 1·18 for amylose (the average value in Table 1), the percentage of the starch soluble in hot water and assessed as amylose can be calculated to be 25%, which may be compared with the estimate of 26% given by Schoch (*op. cit.*) for the amount of amylose in wheat starch.

Results of Control Experiments.—Addition of 1% sodium chloride to solutions of amylose had no effect on the intrinsic viscosity in alkali.

Steam-distillation, under nitrogen, of the wet paste of amylose, sample M_1, to remove butanol, left the intrinsic viscosity in 0·5N-sodium hydroxide unchanged at 2·8. This proved that traces of butanol accompanying amylose when solutions in sodium hydroxide were prepared from the wet paste had no effect on the intrinsic viscosity. Larger quantities of butanol had the effect shown in Table 2, in which the code used is as for Table 1. The intrinsic viscosity has been determined in 0·5N-sodium hydroxide in the presence of the listed amounts of butanol. It is seen that in every case, except for amylose prepared by deacetylation, butanol decreases the viscosity. The decrease occurs during the addition of the first 0·5% of butanol, after which the intrinsic viscosity remains constant. Allied with this is a decrease in the interaction of the

amylose molecules with one another, which is shown by a decrease in the slope of the plot of $\eta_{sp.}/c$ against c as the concentration of butanol is increased, until with 5% of butanol $\eta_{sp.}/c$ has become independent of c.

TABLE 2.

	Concentration of butanol (% v/v)				
	0·0	0·5	1·0	2·5	5·0
Amylose sample *	Intrinsic viscosity in 0·5N-NaOH at 20°				
M_1 (*b*)	3·6	3·0	3·0	3·0	3·0
M_1 (*a*)	2·8	2·3	2·3	—	—
M_1 (*a*) †	2·8	2·3	2·3	—	—
U_6 (*b*)	2·9	2·2	—	—	—
U_6 (*d*)	2·4	—	2·4	—	—

* For meaning of *a*, *b*, and *d*, see p. 4049.
† Wet butanol paste of amylose steam-distilled before being added to NaOH.

DISCUSSION

These results show that the simple elution procedure which was effective for potato starch works equally well for wheat starch. There is a slight difference in that salt is not needed as wheat amylopectin settles readily in distilled water, but as before only fresh undried starch has been used and mechanical stirring has been avoided. The action of oxygen, which rapidly lowers the viscosity of a hot dispersion of potato starch (Baum and Gilbert, *loc. cit.*), has not yet been studied for cereal starches.

It will still be necessary to rely for fractionation on the selective precipitation of amylose (Lansky, Kooi, and Schoch, *J. Amer. Chem. Soc.*, 1949, **71**, 4066) where prior treatment of the starch, as for instance in the production of some commercial starches, has rendered the amylopectin soluble or has insolubilised some of the amylose within the granule. It should be mentioned, however, since it has a bearing on the true molecular size of amylopectin, that Bechtel (*Cereal Chem.*, 1951, **28**, 29) showed that apparently clear solutions of starch prepared by vigorous methods of dispersion contain large numbers of undissolved fragments of granule which can be seen by means of the phase-contrast microscope.

The dependence of the intrinsic viscosity of alkaline solutions of amylose on the method of preparation of the solution (Table 1) lends emphasis to the idea that amylose can be obtained in different configurations in solution (see Husemann and Bartl, *Makromol. Chem.*, 1953, **10**, 183). However, the acetate has a reproducible intrinsic viscosity of 4·8 in chloroform, and on deacetylation gives a reproducible value of 3·0 in 0·5N-sodium hydroxide. Under such conditions, therefore, conclusions can be drawn from intrinsic viscosity as to relative molecular size. The respective values of 4·8 and 3·0 may be compared with the corresponding values of 6·2 and 4·1 obtained in earlier unpublished work for potato amylose (Baum, Bottle, and Gilbert). Wheat amylose has therefore a somewhat smaller molecule than potato amylose. The results for the sample U_6 lead to the conclusion that the more slowly sedimenting granules of wheat contain amylose of lower average molecular weight.

Throughout no difference has been found between the starch of mottled and of normal wheat, and the duplication of results has served rather to illustrate the reproducibility of the methods and measurements.

One of us (H. L. W.) is indebted to Professor H. W. Melville, F.R.S., and to Professor M. Stacey, F.R.S., for the hospitality of the Department during study leave from the Chemistry Department, University of Queensland; another (H. B.) acknowledges a maintenance grant from the D.S.I.R.

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EDGBASTON, BIRMINGHAM, 15.

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A New Synthesis of Chrysene.

By A. D. Jarrett and J. D. Loudon.

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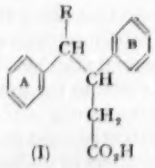
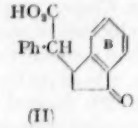
Cyclisation of γ-cyano-βγ-diphenylbutyric acid (I; R = CN) yields the amide (III; R = $CO{\cdot}NH_2$) of 1 : 2 : 3 : 4-tetrahydro-4-oxo-2-phenyl-1-naphthoic acid. Hence by standard methods *trans*-1 : 2 : 3 : 4-tetrahydro-2-phenyl-1-naphthylacetic acid (V; R = $CH_2{\cdot}CO_2H$) and *trans*-1 : 2 : 7 : 8 : 15 : 16-hexahydro-2-oxochrysene (VI) are synthesised and converted into chrysene.

The preponderant formation of an indanone derivative (II) in preference to the tetralone (III; R = CO_2H) during cyclisation of αβ-diphenylglutaric acid (I; R = CO_2H) has been attributed to deactivation of ring A in (I) by the nearer carboxyl group (R) (Badger, Campbell, and Cook, *J.*, 1949, 1084). Similar retarding effects have also been noted in cyclisations of α-arylglutaric acids (Hey and Nagdy, *J.*, 1953, 1894) whereas the related γ-aryl-γ-cyanopimelic acids are readily cyclised without apparent retardation by the cyano-group (*idem*, *J.*, 1954, 1204). It was therefore of interest to examine the behaviour of γ-cyano-βγ-diphenylbutyric acid (I; R = CN). This compound resisted cyclisation by hydrogen fluoride but afforded the tetralone derivative (III; R = $CO{\cdot}NH_2$), together with some αβ-diphenylglutarimide, when treated with polyphosphoric acid.



(I)



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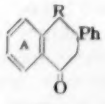
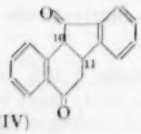


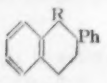
(III)

The formation of an amide from a nitrile under treatment with polyphosphoric acid is frequently observed (cf. Snyder and Elston, *J. Amer. Chem. Soc.*, 1954, **76**, 3039) and the tetralone structure (III; R = $CO{\cdot}NH_2$) assigned to the present compound is fully confirmed by the behaviour of the carboxylic acid which is obtained by hydrolysis. This acid (III; R = CO_2H) was converted into 2-phenylnaphthalene by reduction and dehydrogenation with simultaneous decarboxylation. It was also cyclised to the dione (IV) and this by dehydrogenation afforded the known 3-hydroxy-1 : 2-benzofluorenone. Moreover the availability of (III; R = CO_2H) opens the way to a synthesis of chrysene, which has now been accomplished and should be applicable to a number of chrysene derivatives.

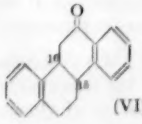
Clemmensen reduction of the acid (III; R = CO_2H) yielded 1-carboxy-2-phenyltetralin (V; R = CO_2H) and this was converted into the homo-acid (V; R = $CH_2{\cdot}CO_2H$) by Newman and Beal's modification of the Arndt–Eistert reaction (*J. Amer. Chem. Soc.*, 1950,



(IV)



(V)



(VI)

72, 5163). This homo-acid and the hexahydro-oxochrysene (VI) which is obtained from it by cyclisation differ markedly from the respective, known isomers of *cis*-structure (Newman, *ibid.*, 1938, **60**, 2947). That they are the hitherto unknown *trans*-compounds is confirmed by reduction of the ketone (VI) to a hexahydrochrysene which corresponds with the known *trans*-isomer in m. p. (Ramage and Robinson, *J.*, 1933, 607) and in ultraviolet absorption spectrum (Askew, *J.*, 1935, 512). Dehydrogenation of this hexahydrochrysene, effected as described by Ramage and Robinson (*loc. cit.*), afforded chrysene.

Experimental

α-(3-Oxoindan-1-yl)-α-phenylacetic Acid.—This acid (II), m. p. and mixed m. p. **153—154°** (Badger, Campbell, and Cook, *loc. cit.*), was isolated in poor yield from cyclisation of αβ-diphenylglutaric acid (0·4 g.) by polyphosphoric acid (from 2 c.c. of syrupy phosphoric acid and 5 g. of phosphoric anhydride) at **100°** (2—3 hr.). The glutaric acid was recovered after attempted cyclisation by hydrogen fluoride in which it appeared to be insoluble.

1 : 2 : 3 : 4-*Tetrahydro*-4-*oxo*-2-*phenyl*-1-*naphthamide* (III; R = $CO{\cdot}NH_2$).—γ-Cyano-βγ-diphenylbutyric acid (2 g.) (Helmkamp, Tanghe, and Plati, *J. Amer. Chem. Soc.*, **1940, 62, 3217**) was heated for 2 hr. with polyphosphoric acid (from 10 c.c. of phosphoric acid and 25 g. of phosphoric anhydride) at **100°**. The cooled mixture was treated with crushed ice and the resultant solid, after being washed with dilute sodium carbonate, was separated into a neutral and an acidic component by fractional crystallisation from acetic acid or, better, by treatment with cold dilute sodium hydroxide solution. The acidic component, which was also the less soluble in acetic acid, was identified by m. p. and mixed m. p. **226—227°** (from acetic acid), and by its infrared spectrum, as αβ-diphenylglutarimide (Found: C, 76·8; H, 5·7; N, 5·4. Calc. for $C_{17}H_{15}O_2N$: C, 76·95; H, 5·7; N, 5·3%) for which Barr and Cook (*J.*, 1945, 440) record m. p. 221—223°. The neutral component afforded **1 : 2 : 3 : 4-*tetrahydro*-4-*oxo*-2-*phenyl*-1-*naphthamide*** as needles, m. p. **200—201°** (from acetic acid) (Found: C, 77·0; H, 6·0; N, 5·3. $C_{17}H_{15}O_2N$ requires C, 76·95; H, 5·7; N, 5·3%). Light absorption in EtOH: max. at **248** and **291** mμ (log **ε** 4·05 and 3·23 respectively). The naphthamide was characterised as the **2 : 4-*dinitrophenylhydrazone***, m. p. 277—279° (decomp.) (from acetic acid) (Found: C, 62·3; H, 4·5; N, 15·6. $C_{23}H_{19}O_5N_5$ requires C, 62·0; H, 4·3; N, 15·7%).

1 : 2 : 3 : 4-*Tetrahydro*-4-*oxo*-2-*phenyl*-1-*naphthoic acid* (III; R = CO_2H) was obtained as colourless needles, m. p. **151—152°** [from benzene–light petroleum (b. p. 60—80°)] when the amide (III; R = $CO{\cdot}NH_2$) (2 g.) was heated (3 hr.) with 5N-sodium hydroxide (25 c.c.) and ethanol (5 c.c.) and the resultant solution was acidified (Found: C, 76·7; H, 5·6. $C_{17}H_{14}O_3$ requires C, 76·7; H, 5·3%). It formed a **2 : 4-*dinitrophenylhydrazone***, m. p. 240—242° (decomp.) (from ethanol) (Found: C, 61·7; H, 3·85; N, 12·8. $C_{23}H_{18}O_6N_4$ requires C, 61·9; H, 4·0; N, 12·55%).

3 : 4 : 10 : 11-*Tetrahydro*-3-*oxo*-1 : 2-*benzofluorenone* (IV) was formed when the foregoing acid (III; R = CO_2H) was cyclised by polyphosphoric acid (40 min. at 100°). It was obtained as needles, m. p. **148—150°** (from methanol) (Found: C, 82·0; H, 5·15. $C_{17}H_{12}O_2$ requires C, 82·2; H, 4·85%). When heated under reflux (5—10 min.) in nitrobenzene containing a crystal of iodine, it afforded **3-hydroxy-1 : 2-benzofluorenone** which was identified by m. p. and mixed m. p. **303—307°** (decomp.), and by its infrared spectrum.

1 : 2 : 3 : 4-*Tetrahydro*-2-*phenyl*-1-*naphthoic Acid* (V; R = CO_2H).—The keto-acid (III; R = CO_2H) (2 g.), amalgamated zinc (5 g.), water (3 c.c.), concentrated hydrochloric acid (7 c.c.), and toluene (4 c.c.) were briskly heated under reflux for 50 hr., concentrated hydrochloric acid (2 c.c.) being added every 10 hr. The organic layer, combined with an ethereal extract of the aqueous layer, afforded after recovery **1 : 2 : 3 : 4-*tetrahydro*-2-*phenyl*-1-*naphthoic acid*** as needles, m. p. **143—144°** (from acetic acid) (Found: C, 81·0; H, 6·3. $C_{17}H_{16}O_2$ requires C, 80·9; H, 6·4%). By reaction with thionyl chloride in benzene the acid afforded the acid chloride and thence, by treatment with ammonia, the corresponding ***amide*** of m. p. **183—184°** (from benzene) (Found: C, 81·05; H, 6·9. $C_{17}H_{17}ON$ requires C, 81·2; H, 6·8%).

In one experiment the reducing mixture after 36 hr. was inadvertently evaporated to dryness and heated at **200—300°** for 3—4 hr. Recovery in benzene, chromatography in benzene on alumina, and sublimation afforded 2-phenylnaphthalene, identified by its infrared spectrum, and by m. p. **100—101°**, alone or in admixture with an authentic sample for which we thank Dr. N. Campbell.

trans-1 : 2 : 3 : 4-*Tetrahydro*-2-*phenyl*-1-*naphthylacetic Acid* (V; R = $CH_2{\cdot}CO_2H$).—The foregoing acid chloride, prepared from 4 g. of the acid (V; R = CO_2H), reacted with ethereal diazomethane to form a crystalline diazo-ketone. To a solution of this diazo-ketone in anhydrous methanol (55 c.c.) there was added, at 20° during 2 hr., a portion (3·8 g.) of a filtered solution prepared from silver benzoate (1 g.) and triethylamine (9·1 g.). The mixture was then heated under reflux for 2 hr. and, after treatment with charcoal, was concentrated *in vacuo*. The gummy product was hydrolysed with 5N-potassium hydroxide (25 c.c.) containing a little ethanol. Acidification of the filtered solution gave **trans-1 : 2 : 3 : 4-*tetrahydro*-2-*phenyl*-1-*naphthylacetic acid*** as colourless prisms, m. p. **136—137°** (from acetonitrile) (Found: C, 80·9; H, 6·6. $C_{18}H_{18}O_2$ requires C, 80·9; H, 6·8%).

trans-1 : 2 : 7 : 8 : 15 : 16-*Hexahydro-2-oxochrysene* (VI) was obtained as neutral product when the foregoing acid (V; R = CH_2·CO_2H) was heated with polyphosphoric acid at 120—130° for 3—4 hr. It formed colourless rhombs, m. p. 118° (from light petroleum, b. p. 60—80°) (Found: C, 86·9; H, 6·3. $C_{18}H_{16}O$ requires C, 87·1; H, 6·5%). Light absorption in EtOH: max. at 253 and 294 mμ (log ε 4·12 and 3·34 respectively). It was characterised as the *semicarbazone*, m. p. 237—239° (decomp.) (from acetic acid) (Found: C, 74·65; H, 6·1; N, 13·5. $C_{19}H_{19}ON_3$ requires C, 74·7; H, 6·3; N, 13·75%). For the *cis*-isomer Newman (*loc. cit.*) records m. p. 75·8—76·8°, and semicarbazone, m. p. 255—258° (decomp.).

trans-1 : 2 : 7 : 8 : 15 : 16-*Hexahydrochrysene*.—The chrysenone (VI) was reduced (24 hr.) as described for the preparation of the tetralin (V; R = CO_2H). The resultant hexahydrochrysene, after chromatography in light petroleum (b. p. 60—80°) on alumina, had m. p. 112—114° (from light petroleum, b. p. 40—60°) (Found: C, 92·25; H, 7·4. Calc. for $C_{18}H_{18}$: C, 92·3; H, 7·7%). Light absorption in EtOH: max. at 266 and 274 mμ (log ε 3·19 and 3·01 respectively). Ramage and Robinson (*loc. cit.*) record m. p. 115°, and by their procedure the present specimen was dehydrogenated to chrysene which was identified by m. p. and mixed m. p. 248—250°, and by its infrared spectrum.

We are indebted to Dr. G. Eglinton for helpful discussion of infrared absorption spectra. Microanalyses were carried out by Mr. J. M. L. Cameron and Miss M. W. Christie: measurements of absorption spectra were made by Mr. G. Milmine.

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Structural Properties and the Relative Electrode Potentials of Synthetic Manganese Dioxides. Part I. The E.M.F. of the Cell $Pt–H_2|HCl,MnCl_2|\beta\text{-}MnO_2–Pt$.

By K. H. MAXWELL and H. R. THIRSK.

[Reprint Order No. 6364.]

In order to compare the relative electrode potentials of the synthetic manganese dioxides the standard electrode potential of the system shown in the Title has been redetermined by use of the cell

$$Pt–Ag,AgCl|HCl,MnCl_2|\beta\text{-}MnO_2–Pt$$

A figure of 1·220 v has been selected, and is employed to calculate the activity function of the electrolyte solutions used in the determination of the relative electrode potentials of the different oxides.

IN the investigation of an electrode system it is important to ascertain the cell reaction; materials for which thermochemical data are available must be used and the calculated and experimental e.m.f. compared. The only suitable form of manganese dioxide is β-MnO_2 (pyrolusite); this oxide has been selected by the Bureau of Standards ("Selected Values of Thermodynamic Properties," New York, 1947). We propose to relate the e.m.f.'s of cells containing the disperse forms of manganese dioxide to that of a similar cell containing β-MnO_2. The present paper is concerned with experiments designed to establish a reference value for the standard electrode potential of the electrode β-$MnO_2|Mn^{++},H^+$ and to provide activity data for the calculation of the relative electrode potentials of the α-, δ-, and γ-oxides.

Four attempts have previously been made to determine the standard electrode potential of β-MnO_2 in acid solution. Brown and Liebhafsky (*J. Amer. Chem. Soc.*, 1930, **52**, 2545) used the cell system $Pt–H_2|Mn(ClO_4)_2,HClO_4|\beta\text{-}MnO_2–Pt$, and obtained potential differences steady to ±1 mv, and, by estimating the values of the activity coefficients from data for similar salts arrived at a value for E° for the β-MnO_2 electrode relative to hydrogen of 1·236 v at 25°. (Unless otherwise stated E° will have this significance in this and the following paper.)

Popoff, Riddick, and Becker (*J. Amer. Chem. Soc.*, 1930, **52**, 2624) employed the same system, but were unable to obtain steady potential differences and concluded that the electrode was irreversible. Hutchinson (*J. Amer. Chem. Soc.*, 1947, **69**, 3051) found the

same erratic behaviour when the platinum foil contact was only partly immersed in the oxide. However, when the foil was completely covered by the oxide slurry he observed reasonably steady potential differences and from his results derived $E^\circ = +1{\cdot}230$ v. Wadsley and Walkley (*J. Electrochem. Soc.*, 1949, **95**, 11), using the cell system Pt–Ag,AgCl|$MnCl_2$,HCl|β-MnO_2–Pt, were unable to obtain steady readings in solutions more dilute than 0·1 m, with the conventional type of oxide electrode. With a much smaller electrode with the MnO_2 formed on a platinum spiral, only one electrode out of several behaved satisfactorily.

The differences in the reported values for E° probably arise from two main causes: small differences in the preparative methods and differing methods of estimating the activity coefficients. The first may give rise to small and variable amounts of impurities in the manganese dioxide lattice affecting the e.m.f. of the cells. With regard to the second, if Brown and Liebhafsky's results are combined with the activity coefficients taken by Hutchinson, the derived value of E° is increased to 1·241 v. Thus it would appear that the main cause of the discrepancies is the method of preparation.

Our procedure, which the foregoing results suggested, was to prepare β-MnO_2 by a standardised method and to try to obtain steady potential differences down to a concentration as small as possible in order to make a graphical extrapolation. The cell system employed was that used by Wadsley and Walkley (*loc. cit.*) and the solutions were made equimolal in manganese chloride and hydrochloric acid. By assuming the cell reaction

$$2Ag + MnO_2 + 4HCl = MnCl_2 + 2H_2O + 2AgCl \quad . \quad . \quad . \quad . \quad (1)$$

and neglecting the very small contributions due to the activity of water, the reversible e.m.f. is given by

$$E = E^\circ_c - (RT/2F)[\ln (a_s/a_a^4)]$$
$$= E^\circ_c - (RT/2F)[\ln (m_{\pm s}^3/m_{\pm a})]$$

For equimolal solutions $m_{\pm s}^3 = 9m^3$; $m_{\pm a}^5 = 81m^8$

By substitution and rearrangement

$$E - 2{\cdot}303RT/2F(\log 9m^5) = E^\circ_c - 2{\cdot}303RT/2F[\log (\gamma_{\pm s}^3/\gamma_{\pm a}^8)]$$

where the subscripts a and s refer respectively to HCl and $MnCl_2$, and E°_c is the standard potential of β-MnO_2 with respect to the silver–silver chloride electrode.

A plot of the left-hand side against a suitable function of the ionic strength will yield E°_c when extrapolated to zero molality. E° can then be readily calculated from the value of the standard electrode potential of the silver–silver chloride electrode, −0·2225 v at 25° (Harned and Ehlers, *J. Amer. Chem. Soc.*, 1932, **54**, 1350).

Experimental

Preparation of β-MnO_2.—Electrolytic manganese (100 g.) (Prep. of samples A, B, and C) or the equivalent amount of manganese carbonate (Prep. of samples D and E) were dissolved in the minimum amount of concentrated nitric acid. The solution was filtered while hot and allowed to cool. The resulting crystals of manganese nitrate were recrystallised three times from a small amount of water. The purified solid was decomposed at 130—140°, in a stream of air to remove oxides of nitrogen and water vapour. When decomposition was nearly complete, the whole was poured into water and stirred, and the solution filtered. The dioxide was dried in air at 120°, ground in an agate mortar, and boiled with 1:1 nitric acid and then with water. It was next dried in air at 160°, ground again, and finally heated to 400° in a slow stream of oxygen. The product was a dense, dark grey powder. Analysis showed it to be stoicheiometric MnO_2 and the *X*-ray diffraction pattern agreed in detail with that published in the A.S.T.M. index.

Silver–silver chloride electrodes were prepared by Brown's method (*J. Amer. Chem. Soc.*, 1934, **56**, 646). The cell was of the convential H type, one limb of which contained the silver–silver chloride electrode, and the other the MnO_2 powder completely covering a small piece of foil sealed into a soft glass tube, which gave electrical contact.

Manganese chloride ("AnalaR" grade) was twice recrystallised from water. A stock solution in distilled water was prepared and analysed and all solutions were made by dilution. Constant-boiling hydrochloric acid was prepared by Foulk and Hollingsworth's method (*J. Amer.*

Chem. Soc., 1923, **45**, 122) and from this a stock 0·2m-solution was made up and used for the preparation of the electrolyte.

All measurements were made at 25° with a potentiometer accurate to 0·1 mv. Altogether, seven solutions were employed, the molalities of each component being 0·1, 0·05, 0·02, 0·01, 0·005, 0·002, 0·001, and all solutions were equimolal in manganous chloride and hydrochloric acid.

The oxide was ground well with the electrolyte and soaked for several days. The cell was set up with fresh electrolyte and measurements were made for two days; the electrolyte was then renewed and readings taken for a further two days. The potential differences remained

	E.M.F. in volts				
Molality (m)	A	B	C	D	E
0·1	0·8792	0·8799	0·8812	0·8906	0·8871
0·05	0·8343	0·8348	0·8361	0·8458	0·8419
0·02	0·7757	0·7762	0·7777	0·7876	0·7838
0·01	0·7311	0·7310	0·7325	0·7425	0·7372
0·005	0·6850	0·6849	0·6860	0·6962	0·6902
0·002	0·6254	0·6257	0·5274	0·6369	0·6314
0·001	0·5812	0·5815	0·5832	0·5928	0·5861

steady over the final 24 hr. and are the values recorded in the Table. When changing to a fresh electrolyte concentration the previous solution was decanted and the oxide ground with the new solution, allowed to settle, and decanted again. This was repeated three times for each change of electrolyte. The final values for the e.m.f. were those recorded after the second sample of electrolyte had been introduced. In all cases the final equilibrium value remained constant to 0·1 mv during 24 hr. except for the two most dilute solutions where fluctuations of the order ±0·3 mv were observed.

The e.m.f.'s were extrapolated by Hitchcock's method (*J. Amer. Chem. Soc.*, 1928, **50**, 2076, according to eqn. 2). The extrapolations yielded the following values for the standard electrode potential when converted from the silver–silver chloride scale to the hydrogen scale: A, $1{\cdot}220_2$; B, $1{\cdot}220_7$; C, $1{\cdot}222_2$; D, $1{\cdot}231_6$; E, $1{\cdot}226_0$.

Discussion

Striking features of the results are the widely differing values found for the five samples and the constancy with which the differences are maintained in all the solutions. Preparations A and B gave an e.m.f. within 1 mv of one another at all concentrations, although the magnitude of the difference varies somewhat. The e.m.f. of the cell containing oxide C was about 2 mv greater than the cell with oxide A, while preparations D and E were about 12 and 6 mv respectively greater. In view of the close agreement between samples A and B and because these are also the lowest values we have tentatively taken the value E° to be +1·220 v as the standard electrode potential of β-MnO_2 in acid solution. According to Wadsley and Walkley (*loc. cit.*) a calculation of the e.m.f. of the cell used led to a figure of 1·229 v. This calculation assumed the values for the entropy and heat of formation of manganese dioxide determined by Kelley and Moore (*J. Amer. Chem. Soc.*, 1943, **65**, 782) and Shomate (*ibid.*, p. 785) and the free energy of formation of the manganous ion from the heat of dilution of hydrochloric acid and the free energies of the chloride ion and water from the National Bureau of Standards "Tables of Selected Values of Thermodynamic Properties" (Nat. Bur. Stand., Washington, 1947).

It is considered that our value of 1·220 v, together with the reproducibility of the individual measurements, is sufficient justification for assuming the reversible reaction for the behaviour of the MnO_2 electrode in the cell we have selected for the comparison of the e.m.f.'s of the various oxides to be that written in eqn. 1. In Part II (following paper) we have related the relative electrode potentials of the disperse forms of manganese dioxide to this value and used it to calculate the activity function of the electrolyte solutions employed. This is a somewhat arbitrary procedure as it assumes that the samples A and B represent the oxide in its most stable form. Any absolute error for the derived values of E° for the disperse oxides can be ascribed to this choice; the relative values will be unaffected.

The differing results for β-MnO_2 have not been explained. Analysis showed them all

to be stoicheiometric MnO_2 within the accuracy of the analytical method and all the *X*-ray diffraction patterns were identical. The difierences might be due to very small traces of other elements incorporated in the lattice during preparation and thus modifying the free energy of formation. Spectrographic analysis detected very small traces of iron in all the oxides. Since the limit of the sensitivity of this method can be about 5 p.p.m., we estimate that the amount of iron in these oxides cannot be much greater than *ca.* 10 p.p.m. and is certainly less than 100 p.p.m. No estimate of the relative amounts of the impurity in each oxide could be made, although the lines of the iron spectrum seemed to be weaker in samples A, B, and C than in the others. The widely differing results obtained by other workers may be caused by the presence of varying traces of impurity undetected by ordinary analytical methods and, to a greater or less degree, of strain in the oxide according to the method of preparation.

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Structural Properties and the Relative Electrode Potentials of Synthetic Manganese Dioxides. Part II. The Characterisation and the Relative Electrode Potentials of the α-, γ-, and δ-Oxides.*

By K. H. MAXWELL and H. R. THIRSK.

[Reprint Order No. 6363.]

Analytical data and structural information obtained by electron microscopy and *X*-ray and electron diffraction, relevant to the synthetic α-, γ-, and δ-manganese dioxides used in the e.m.f. experiments are set out in detail; the nomenclature adopted is defined. Reasons are advanced for the particular structural form of some of the oxides and for the changes in structure on sintering and, with certain preparations, on sintering after leaching in order to remove a proportion of the foreign ions present from the material.

The relative electrode potentials of the preparations have been determined with respect to a preparation of β-MnO_2 selected as a standard. Chemically prepared γ-MnO_2 in presence of NH_4^+ and K^+ had similar e.m.f.'s, 30—35 mv greater than the value of β-MnO_2; commercial γ-oxides had similar values. Whilst the e.m.f.'s of the electrolytically prepared γ-oxides were similar, the fluctuations in value were greater than with the chemical preparations; there was no correlation between electrode potential and available oxygen for the γ-preparations. The e.m.f.'s of the α-oxides were of the same order as those of the γ-oxides but well crystallised samples all had a standard electrode potential very near to 1·252 v independent of the nature of the foreign ion. There was a regular change in potential as the γ-phase was converted into the α-phase. The e.m.f.'s of the δ-oxides in presence of sodium and potassium were about 50 mv greater, and with calcium and barium 60—70 mv greater than the β-MnO_2 value; the potentials were somewhat unsteady. The e.m.f. rose with the temperature on annealing to a maximum value for preparations heated at 275—300° c, reaching a value of 65—75 mv for sodium and potassium, and 80 mv for calcium and barium preparations. At this stage α-MnO_2 was detectable in the phase by *X*-ray analysis. There is evidence for the reaction of the δ-oxides with the electrolyte at low acid concentrations. An explanation is given for the results of the e.m.f. measurements.

THE industrial importance of the manganese dioxides has recently stimulated interest in synthetic materials prepared under controlled conditions. Certain properties of the oxides have been measured in an attempt to correlate them with their structure. *E.g.*, Moore, Ellis, and Selwood (*J. Amer. Chem. Soc.*, 1950, **72**, 856) examined the magnetic and

* Part I, preceding paper.

crystallographic properties of certain preparations but few results have been published concerning the e.m.f.'s of cells containing synthetic forms of MnO_2. It has been observed that the open-circuit voltages of dry dells made with these oxides are higher than those with β-MnO_2 (Skewes, Wadsley, and Walkley, *Austral. J. Appl. Sci.*, 1952, **3**, 368); a few measurements on the γ-oxides were also reported by Wadsley and Walkley (*J. Electrochem. Soc.*, 1949, **95**, 11).

These workers measured the e.m.f. of the cell Ag–AgCl|$MnCl_2$,HCl|γ-MnO_2–Pt and found a rough correlation between e.m.f. and the active oxygen of the γ-MnO_2 sample. The e.m.f. was some 40 mv higher than that of the cell containing β-MnO_2.

We now describe the results of observations of electrode potentials for some controlled preparations of oxides of known structural type; this is preceded by a summary of the structural nature of our preparations. In Part I an account was given of the design of a cell and of a generally suitable method for the determination of the potentials of the oxide, and of the establishment of a thermodynamically suitable standard of reference using β-MnO_2.

Our attention is confined to a description of four groups of oxides: α-MnO_2, β-MnO_2, γ-MnO_2, and δ-MnO_2, and as confusion exists in the general nomenclature applied to the manganese dioxide we define the terms as follows:

α-MnO_2 refers to oxides having tetragonal or pseudo-tetragonal unit cells with a large axial ratio, approximate dimensions being $a_o \approx b_o \approx 9{\cdot}8$ Å; $c_o \approx 2{\cdot}85$ Å, and $\beta \approx 90°$ (Byström and Byström, *Acta Cryst.*, 1950, **3**, 1946). A foreign-metal ion, A, such as potassium or barium and perhaps ammonium (Butler and Thirsk, *ibid.*, p. 146), seems to be an essential constituent of the structure and an approximate general formula is $A_xMn_8O_{16}$, where x is usually less than unity.

β-MnO_2 (pyrolusite), the selected reference oxide, can be prepared by the thermal decomposition of manganese nitrate. It is the best-known oxide and its structure has been investigated several times and found to be of the rutile type; the electrochemical behaviour has been discussed in Part I (*loc. cit.*).

γ-MnO_2, often produced by precipitation from solution and apparently always formed by electrolytic deposition at the anode (Cole, Wadsley, and Walkley, *J. Electrochem. Soc.*, 1947, **92**, 133), is poorly crystalline, the *X*-ray pattern showing several diffuse lines which can be indexed on the basis of an orthorhombic unit cell with the approximate dimensions $a_o \approx 4{\cdot}4$ Å; $b_o \approx 9{\cdot}3$ Å; $c_o \approx 2{\cdot}83$ Å (Byström, *Acta Chem. Scand.*, 1949, **3**, 163).

δ-MnO_2 (manganous manganite) is an extremely finely divided material giving prominent diffractions near $d_{hkl} = 1{\cdot}42$, 2·44, 3·63, and 7·3 Å. It is formed either by the alkaline oxidation of manganous hydroxide (Feitknecht and Marti, *Helv. Chim. Acta*, 1945, **28**, 129, 149) or by the decomposition of permanganates by hydrochloric acid (McMurdie, *J. Electrochem. Soc.*, 1944, **86**, 313).

Experimental

Preparative and Structural Investigation.—Many samples of the above oxides were prepared, sintered in oxygen, analysed, and examined by *X*-ray and electron diffraction and electron microscopy. For details of the experimental techniques see Butler, Maxwell, and Thirsk, *J.*, 1952, 4210; Butler and Thirsk, *J. Electrochem. Soc.*, 1953, **100**, 347.

General details relating to the classification of the α-, γ-, and δ-oxides are given in Table 1.

Electrochemical.—A cell similar to that used by Wadsley and Walkley (*loc. cit.*) was used and, the same cell reaction being assumed as for β-MnO_2, E is given by

$$E = E^\circ - (\boldsymbol{RT}/2\boldsymbol{F})[\ln(a_{\pm s}^3/a_{\pm a}^8)] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where $a_{\pm s}$ and $a_{\pm a}$ are the mean activities of manganous chloride and hydrochloric acid (cf. Part I, p. 4055). In order to reduce the number of measurements and at the same time to obtain as great a variation as possible in the ratio of the activities of manganous chloride and hydrochloric acid, five solutions were employed, being 0·01, 0·03, 0·05, 0·07, and 0·09 m with respect to hydrochloric acid, while the remainder of the ionic strength, μ, was kept constant at 0·1 with manganous chloride of molality 0·0300, 0·0233, 0·0167, 0·0100, and 0·0033.

All measurements were made at 25°. As preliminary measurements had shown that a few

of the oxide electrodes were easily polarised even by the small current taken in balancing a potentiometer, an electrometer triode was incorporated in the measuring circuit together with a potentiometer accurate to $\pm 0{\cdot}2$ mv. The oxide samples were ground with the first electrolyte and soaked in this solution for several days before the cell was set up. Three electrodes from each oxide sample were used and the e.m.f.'s measured over several days. The electrolyte was then renewed, the oxide reground with the fresh electrolyte and readings were taken for a further few days. The e.m.f. was usually found to stay constant within 1—2 mv over the latter period and this value was recorded. The electrolyte was then changed by decantation and washing with the next electrolyte and the whole procedure repeated.

In order to evaluate the activity factor in equation (1) the value of E° obtained from the experiments in Part I of this series was employed. Thus the e.m.f.'s of the cells containing the disperse forms of manganese dioxide were put on to the hydrogen scale by measuring them relative to Preparation A (Part I, *loc. cit.*) of β-MnO_2. Three electrodes were made up from each oxide sample and their e.m.f.'s were measured in five solutions. The mean values of E° are given in Table 1, together with an estimate of the probable error derived from the standard deviation.

TABLE 1.

Preparation	Formula	Phase *	E° (v)
1. Oxidation of acid manganous sulphate solution by ammonium persulphate.			
(*a*) Dried at 60°	$MnO_{1\cdot95}$	γ	$1{\cdot}253 \pm 0{\cdot}001_4$
(*b*) Identical with (*a*) dried at room temp.	$(NH_4)_{0\cdot02}MnO_{1\cdot95}$	α, γ (e)	$1{\cdot}265 \pm 0{\cdot}001_0$
(*c*) Identical with (*a*) dried at 60°	$(NH_4)_{0\cdot02}MnO_{1\cdot89}$	α, γ (e)	$1{\cdot}261 \pm 0{\cdot}001_0$
(*d*) Identical with (*a*) dried at 60°	$(NH_4)_{0\cdot02}MnO_{1\cdot89}$	α, γ (e)	$1{\cdot}261 \pm 0{\cdot}001_0$
(*e*) Prep. (*a*) heated to 200° in O_2	$MnO_{1\cdot97}$	MnO_2	$1{\cdot}248 \pm 0{\cdot}001_0$
(*f*) Prep. (*b*) heated to 200° in O_2	$(NH_4)_{0\cdot02}MnO_{1\cdot94}$	α, γ (e)	$1{\cdot}257 \pm 0{\cdot}001_0$
(*g*) Prep. (*b*) heated to 400° in O_2	—	α	$1{\cdot}252 \pm 0{\cdot}001_6$
2. Oxidation of a solution of ($MnSO_4 + H_2SO_4 + KNO_3$) by $KMnO_4$			
(*a*) Dried at room temp.	$K_{0\cdot03}MnO_{1\cdot93}$	α, γ (e)	$1{\cdot}266 \pm 0{\cdot}001_3$
(*b*) Dried at 60°	$K_{0\cdot03}MnO_{1\cdot91}$	α, γ (e)	$1{\cdot}263 \pm 0{\cdot}001_3$
(*c*) Prep. (*a*) heated to 200° in O_2	$K_{0\cdot03}MnO_{1\cdot91}$	α, γ (e)	$1{\cdot}256 \pm 0{\cdot}001_3$
(*d*) Prep. (*b*) heated to 200° in O_2	$K_{0\cdot03}MnO_{1\cdot94}$	α, γ (e)	$1{\cdot}256 \pm 0{\cdot}001_3$
3. $KMnO_4$ added to an acid solution of $MnSO_4$ in three portions. After each addition the MnO_2 was filtered off and dried.			
(*a*) First ppt.	$K_{0\cdot03}MnO_{1\cdot97}$	γ, α (t)	$1{\cdot}254 \pm 0{\cdot}001_0$
(*b*) Second ppt.	$K_{0\cdot06}MnO_{1\cdot94}$	γ, α (e)	$1{\cdot}261 \pm 0{\cdot}001_0$
(*c*) Third ppt.	$K_{0\cdot09}MnO_{1\cdot92}$	α, γ (t)	$1{\cdot}282 \pm 0{\cdot}001_4$
4. Hydrochloric acid added dropwise to a boiling $KMnO_4$ soln.			
(*a*) Dried at room temp.	$K_{0\cdot37}MnO_{2\cdot00}$	δ	$1{\cdot}266 \pm 0{\cdot}001_6$
(*b*) Heated to 120° in O_2	$K_{0\cdot37}MnO_{1\cdot96}$	δ	$1{\cdot}275 \pm 0{\cdot}001_0$
(*c*) ,, 200 ,,	$K_{0\cdot37}MnO_{1\cdot93}$	δ	$1{\cdot}280 \pm 0{\cdot}001_0$
(*d*) ,, 260 ,,	$K_{0\cdot37}MnO_{1\cdot91}$	δ	$1{\cdot}284 \pm 0{\cdot}001_0$
(*e*) ,, 275 ,,	$K_{0\cdot37}MnO_{1\cdot91}$	δ, α (t)	$1{\cdot}292 \pm 0{\cdot}001_0$
(*f*) ,, 300 ,,	$K_{0\cdot37}MnO_{1\cdot90}$	δ, α (t)	$1{\cdot}290 \pm 0{\cdot}001_3$
(*g*) ,, 400 ,,	$K_{0\cdot37}MnO_{1\cdot89}$	α	$1{\cdot}277 \pm 0{\cdot}001_3$
(*h*) ,, 500 ,,	$K_{0\cdot37}MnO_{1\cdot82}$	α	$1{\cdot}252 \pm 0{\cdot}001_6$
5. Hydrochloric acid added dropwise to a boiling $NaMnO_4$ soln.			
(*a*) Dried at room temp.	$Na_{0\cdot22}MnO_{1\cdot99}$	δ	$1{\cdot}270 \pm 0{\cdot}001_0$
(*b*) Heated to 120° in O_2	$Na_{0\cdot22}MnO_{1\cdot97}$	δ	$1{\cdot}273 \pm 0{\cdot}001_6$
(*c*) ,, 200 ,,	$Na_{0\cdot22}MnO_{1\cdot93}$	δ	$1{\cdot}278 \pm 0{\cdot}001_0$
(*d*) ,, 250 ,,	$Na_{0\cdot22}MnO_{1\cdot92}$	δ	$1{\cdot}281 \pm 0{\cdot}001_1$
(*e*) ,, 275 ,,	$Na_{0\cdot22}MnO_{1\cdot91}$	δ	$1{\cdot}285 \pm 0{\cdot}001_3$
(*f*) ,, 300 ,,	$Na_{0\cdot22}MnO_{1\cdot91}$	δ, α (t)	$1{\cdot}282 \pm 0{\cdot}001_0$
(*g*) ,, 400 ,,	$Na_{0\cdot22}MnO_{1\cdot90}$	α	$1{\cdot}272 \pm 0{\cdot}001_6$
(*h*) ,, 500 ,,	$Na_{0\cdot22}MnO_{1\cdot89}$	α	$1{\cdot}250 \pm 0{\cdot}001_3$
6. Hydrochloric acid added dropwise to a boiling $Ba(MnO_4)_2$ soln.			
(*a*) Dried at room temp.	$Ba_{0\cdot13}MnO_{2\cdot00}$	δ	$1{\cdot}276 \pm 0{\cdot}002_3$
(*b*) Heated at 120° in O_2	$Ba_{0\cdot13}MnO_{1\cdot98}$	δ	$1{\cdot}285 \pm 0{\cdot}001_3$
(*c*) ,, 200 ,,	$Ba_{0\cdot13}MnO_{1\cdot95}$	δ	$1{\cdot}297 \pm 0{\cdot}002_3$
(*d*) ,, 400 ,,	$Ba_{0\cdot13}MnO_{1\cdot94}$	δ	
(*e*) ,, 500 ,,	$Ba_{0\cdot13}MnO_{1\cdot91}$	α	
(*f*) ,, 580 ,,	$Ba_{0\cdot13}MnO_{1\cdot86}$	p	

TABLE 1. (*Continued.*)

Preparation	Formula	Phase *	E° (v)
7. Prep. 6 boiled with 4N-HNO_3 for 4 hr.			
(*a*) Dried at 120°	$Ba_{0\cdot02}MnO_{1\cdot97}$	α	$1\cdot264 \pm 0\cdot001_2$
(*b*) Heated at 400° in O_2	$Ba_{0\cdot02}MnO_{1\cdot98}$	α	$1\cdot253 \pm 0\cdot001_9$
8. Hydrochloric acid added dropwise to a boiling $Ca(MnO_4)_2$ soln.			
(*a*) Dried at room temp.	$Ca_{0\cdot12}MnO_{1\cdot99}$	δ	$1\cdot288 \pm 0\cdot001_7$
(*b*) Heated at 200° in O_2	$Ca_{0\cdot12}MnO_{1\cdot97}$	δ	$1\cdot304 \pm 0\cdot002_0$
(*c*) ,, 400 ,,	$Ca_{0\cdot12}MnO_{1\cdot93}$	δ	
(*d*) ,, 500 ,,	$Ca_{0\cdot12}MnO_{1\cdot86}$	α	
(*e*) ,, 580 ,,	$Ca_{0\cdot12}MnO_{1\cdot94}$	q	
9. Prep. 8 boiled with 4N-HNO_3 for 4 hr.			
(*a*) Dried at 120°	$Ca_{0\cdot01}MnO_{1\cdot98}$	α	$1\cdot261 \pm 0\cdot001_0$
(*b*) Heated at 400 in O_2	$Ca_{0\cdot01}MnO_{1\cdot95}$	α	$1\cdot258 \pm 0\cdot001_1$
10. B.D.H. sample.			
(*a*) As obtained	$K_{0\cdot21}MnO_{1\cdot96}$	δ	$1\cdot276 \pm 0\cdot001_0$
(*b*) Heated at 120° in O_2	$K_{0\cdot21}MnO_{1\cdot94}$	δ	$1\cdot279 \pm 0\cdot001_0$
(*c*) ,, 200 ,,	$K_{0\cdot21}MnO_{1\cdot93}$	δ	$1\cdot281 \pm 0\cdot001_3$
(*d*) ,, 250 ,,	$K_{0\cdot21}MnO_{1\cdot92}$	δ	$1\cdot292 \pm 0\cdot001_3$
(*e*) ,, 275 ,,	$K_{0\cdot21}MnO_{1\cdot92}$	δ, α (t)	$1\cdot296 \pm 0\cdot001_6$
(*f*) ,, 300 ,,	$K_{0\cdot21}MnO_{1\cdot91}$	δ, α (t)	$1\cdot294 \pm 0\cdot001_2$
(*g*) ,, 400 ,,	$K_{0\cdot21}MnO_{1\cdot90}$	α	$1\cdot284 \pm 0\cdot001_0$
(*h*) ,, 500 ,,	$K_{0\cdot21}MnO_{1\cdot90}$	α	$1\cdot252 \pm 0\cdot001_6$
11. Electrolytic deposition at a Pt anode from an acid solution of $MnSO_4$ at 75°.			
(*a*) Dried at room temp.	$MnO_{1\cdot96}$	γ	$1\cdot258 \pm 0\cdot001_0$
(*b*) Identical with (*a*)	$MnO_{1\cdot95}$	γ	$1\cdot254 \pm 0\cdot001_0$
(*c*) Identical with (*a*)	$MnO_{1\cdot96}$	γ	$1\cdot258 \pm 0\cdot001_0$
12. Prep. 11 boiled with 2N-HNO_3 for 4 hr. Dried at room temp.			
(*a*)	$MnO_{1\cdot98}$	γ	$1\cdot255 \pm 0\cdot001_2$
(*b*)	$MnO_{1\cdot98}$	γ	$1\cdot255 \pm 0\cdot001_0$
(*c*)	$MnO_{1\cdot97}$	γ	$1\cdot255 \pm 0\cdot001_0$
13. Commercial electrolytic preparations from various sources.			
(*a*)	$MnO_{1\cdot92}$	γ	$1\cdot255 \pm 0\cdot001_5$
(*b*)	$MnO_{1\cdot93}$	γ	$1\cdot252 \pm 0\cdot001_3$
(*c*)	$MnO_{1\cdot92}$	γ	$1\cdot251 \pm 0\cdot001_1$
(*d*)	$MnO_{1\cdot96}$	γ	$1\cdot253 \pm 0\cdot001_7$
(*e*)	$MnO_{1\cdot93}$	γ	$1\cdot255 \pm 0\cdot001_4$
(*f*)	$MnO_{1\cdot91}$	γ	$1\cdot251 \pm 0\cdot001_2$
(*g*)	$MnO_{1\cdot97}$	γ	$1\cdot250 \pm 0\cdot001_1$
(*h*)	$MnO_{1\cdot91}$	γ	$1\cdot235 \pm 0\cdot002_6$
14. Samples 13 boiled with 2N-HNO_3 for 4 hr. Dried at room temp.			
(*a*)	$MnO_{1\cdot98}$	γ	$1\cdot238 \pm 0\cdot001_0$
(*b*)	—	γ	$1\cdot242 \pm 0\cdot001_2$
(*c*)	—	γ	$1\cdot250 \pm 0\cdot001_0$
(*d*)	$MnO_{1\cdot97}$	γ	$1\cdot251 \pm 0\cdot001_0$
(*e*)	$MnO_{1\cdot97}$	γ	$1\cdot242 \pm 0\cdot001_0$
(*f*)	—	γ	$1\cdot246 \pm 0\cdot001_0$
(*g*)	—	γ	$1\cdot242 \pm 0\cdot001_0$
(*h*)	$MnO_{1\cdot95}$	γ	$1\cdot247 \pm 0\cdot001_0$

* t = trace; e = equal amounts; p = very poorly crystallised α-MnO_2 + α-Mn_2O_3; q = poorly crystallised α-MnO_2; decomp.

DISCUSSION

Structural Properties.—Initially the reason for the production of α- and γ-forms of the oxides from Preparation 1 (see Table 1) was not clear; in certain cases γ-MnO_2 was obtained with strong diffractions at 4·03, 2·42, 2·12, and 1·63 Å whilst with other preparations, an apparently identical procedure being used, a mixture of α- and γ-forms in approximately equal amounts was precipitated. With Preparation 2 (*a*), potassium permanganate being

used as oxidising agent, a mixed phase invariably resulted; other workers have reported either γ-MnO_2 (Moore, Ellis, and Selwood, *loc. cit.*) or α-MnO_2 (Cole, Wadsley, anf Walkley, *loc. cit.*).

Preparation 3 was carried out to investigate this matter further. To an acid solution of manganous sulphate without potassium nitrate the required quantity of potassium permanganate for complete precipitation was added in three equal portions. After each addition the precipitate was filtered off. The precipitate first collected was found to be γ-MnO_2 with a trace of α-MnO_2, very weak reflections being observed at interplanar spacings corresponding to the strongest lines of the α-MnO_2 pattern. The second precipitate contained both the α- and the γ-phase in about equal amounts, the strong lines of the two phases having approximately equal intensities. The last-formed portion of the precipitate was found to be almost α-MnO_2, with only a faint reflection at $d_{hkl} = 4{\cdot}03$ Å indicating the presence of a trace of the γ-oxide.

The best substantiated idea of the structure of the γ-MnO_2 is due to Byström (*loc. cit.*) who pointed out that the lines of the γ-MnO_2 pattern are those which are common to ramsdellite and pyrolusite, if the pyrolusite lines are indexed on the basis of a unit cell having twice the value of the normal b_o axis. It was therefore suggested that γ-MnO_2 was intermediate in structure between ramsdellite and pyrolusite. In a later paper Byström and Byström (*loc. cit.*) stated that the arrangement of manganese ions probably changes from that of ramsdellite to pyrolusite at random since the network of oxygen ions is essentially the same in both structures. In order to explain the fact that with many synthetic preparations involving the precipitation of the dioxide from solution either the α- or the γ-form resulted. Byström and Byström suggested that the primary product is the formation of double strings of octahedra common to both α-MnO_2 and ramsdellite. If a sufficient concentration of large metal ions is present these double strings cluster round then in the α-MnO_2 manner. If there are too few or no large ions in solution the double strings can join in a disordered ramsdellite arrangement and by rearrangement in the boiling solution are converted into the structure known as γ-MnO_2.

These ideas are supported by the results from Preparation 3. The first precipitate, formed when the concentration of potassium ions in solution was small is very largely the γ-phase. As the concentration of potassium ions increased the amount of γ-MnO_2 decreased and the final precipitate was almost entirely α-MnO_2. As a mixed phase also resulted from Preparation 1, it is probable that the ammonium ion, which has approximately the same ionic radius as the potassium ion, is also acting similarly as a necessary component of the oxide.

Electron microscopy showed that the α-phase in both Preparations 1 and 2 existed as needles of maximum length 1μ in Preparation 1 and much smaller in 2, and the general details are discussed at some length by Butler and Thirsk (*loc. cit.*). The c_o axis of the unit cell is parallel to the long axis of the crystals even on this microscopic scale and the orientation is the same as that reported from *X*-ray studies on the rare macroscopic single crystals of cryptomelane and hollandite (Byström and Byström, *loc. cit.*; Ramsdell, *Amer. Mineralogist*, 1943, **28**, 497).

Preparation 4 and the commercial sample Preparation 10 show the four diffuse lines characteristic of the δ-MnO_2 *X*-ray pattern. Heating to 250°c made little difference apart from a slight sharpening of the lines; on heating to 275° extra faint lines appeared at spacings of 2·39, 2·15, and 1·83 Å corresponding to the 121, 301, and 141 reflections of α-MnO_2: when heated to 400° the complete α-MnO_2 pattern was obtained and the crystallinity was slightly improved by heating to 500°. With Preparation 5, the δ-MnO_2 produced from the sodium permanganate did not yield α-MnO_2 diffractions until the oxide had been heated to 300°, whereupon faint reflections were observed.

When examined by electron microscopy δ-MnO_2 appeared to consist of irregular plates of very small size. The α-MnO_2, formed by heating the δ-oxide containing potassium, existed as needles similar to those already described but when sodium was the third element no preferred direction of growth and no apparent orientation of unit cell with the external morphology of the crystallites was detected. However the greater sharpness of the 002 reflection in the *X*-ray pattern than of the other lines indicated

that the crystals were also more ordered parallel to the c_o oxis. The electron micrographs of samples of Preparation 4 (300°) and Preparation 10 (300°) in general appear like δ-MnO_2 but by refining the method of dispersion by means of a 1% collodion solution, Mr. E. H. Boult (of these laboratories) was able to show that whilst the majority of the material was typically δ-MnO_2, 3—4% existed as minute needles characteristic of α-MnO_2. Unfortunately, owing to the dispersion necessary to reveal the morphology of the preparation an adequate local concentration for an electron-diffraction pattern was not discovered.

The actual structure of δ-MnO_2 is not known although two proposals have been made as to the probable arrangement in the oxide. Feitknecht and Marti (*loc. cit.*) suggested that it had a layer lattice and was derived from the manganous hydroxide structure which is of the cadmium type. This idea draws support from the preparation of the δ-oxide by oxidation of manganous hydroxide, and virtually the suggestion is that the structure of the δ-MnO_2 can be derived from that of manganous hydroxide by the replacement of manganous and hydroxyl ions by those of the tervalent manganese and oxygen. This idea is unconvincing since the oxide can equally well be made by decomposing permanganates by hydrochloric acid. It appears that the principal evidence in favour of this structure is that the three outer lines of the δ-MnO_2 diffraction pattern have spacings which are submultiples of the line at 7·3 Å, which might indicate a prominent basal plane characteristic of a layer lattice.

McMurdie (*loc. cit.*) considered the δ-oxide to have a poorly crystalline α-MnO_2 arrangement. The four diffuse lines which constitute the δ-MnO_2 *X*-ray pattern can be indexed as 110, 220, 121, and 002 reflections from a lattice based on a tetragonal unit cell with dimensions $a_o = 10{\cdot}3$ Å, $c_o = 2{\cdot}83$ Å. We have noted that this phase, like α-MnO_2, is only formed when a large excess of a suitable foreign cation is present and we also favour a distorted α-MnO_2 arrangement as providing the most likely picture of the structure.

The analytical figures of Table 1 are of interest in connection with the transition of δ-MnO_2 to α-MnO_2. The oxides were analysed for manganese, available oxygen, and the foreign cation. It is common practice, especially in mineralogical papers, to express the percentage of the foreign-metal ion as its oxide; manganese as MnO; to include the oxygen with the determined available oxygen, and to express the whole as total oxygen. In the analyses in Table 1 manganese is assumed to be present as MnO while the extra oxygen is the experimentally found available oxygen. The foreign ion is not expressed as an oxide.

As precipitated, δ-MnO_2 contains almost the stoicheiometrically required quantity of available oxygen, but this diminishes steadily as the oxide is heated at increasing temperatures. If we associate this decrease in available oxygen with the entry of the foreign metal into sites in the lattice, the process would seem to occur continuously over the range 100—400° and to be practically complete at the latter temperature. The approximate general formula for α-MnO_2 being $A_xMn_8O_{16}$, the oxides may be considered, as with the similar naturally occurring minerals cryptomelane, psilomelane, and hollandite, to be semiconductors and in the case of these minerals the formulæ may be written respectively as

$$K_{2\delta}{}^{+}Mn_{\delta}{}^{2+}Mn_{(8-\delta)}{}^{4+}O_{16}, \quad Ba_{\delta}{}^{2+}Mn_{(5-\delta)}{}^{4+}O_{10},(2-\delta)H_2O,$$

and

$$Ba_{\delta}{}^{2+}Mn_{\delta}{}^{2+}Mn_{(8-\delta)}{}^{4+}O_{16},(2—5)H_2O$$

(Rees, "Chemistry of the Defect Solid State," Methuen, 1954, p. 88), the amount of foreign ion entering the lattice directly controlling the relative quantity of Mn^{2+} and Mn^{4+} ions present. A similar formulation could be employed with the synthetic materials. In the structural analysis of hollandite Byström and Byström found that the large metal (Ba^{++}) ions occupied positions in the "tunnels" formed between the strings of MnO_6 octahedra; they came to the conclusion that a maximum of only one large metal ion per unit cell was allowable, corresponding to $x = 1$ in the general formula. Our analyses, however, show that both potassium and sodium enter the lattice continuously up to $x = 2$, when the formula could by written $(K_2O)Mn_8O_{15}$ and n in MnO_n would be 1·88. This suggests that the potassium and sodium atoms occupy sites additional to the one per unit cell suggested by Byström and Byström.

If, as with Preparations **6** and **8**, the foreign ions are barium and calcium a somewhat different state of affairs exists. On heating to 400° three diffuse lines were obtained and these could be indexed as the 200, 121, and 002 reflections of a structure based on a unit cell having $a_o = 10{\cdot}5$ Å and $c_o = 2{\cdot}82$ Å. The designation δ-MnO_2 is retained for these preparations in spite of its not comforming completely to our definition. On heating to 500° a poorly resolved α-MnO_2 pattern was obtained from the product. Attempts to improve the crystallinity by heating to 580° were unsuccessful for no sharpening of the α-MnO_2 diffractions took place and, in addition, the oxide started to decompose, a pattern of α-Mn_2O_3 (bixbyite) appearing. The analyses show, as in the case of the sodium and potassium compounds, a similar decrease in available oxygen content on heating. In this case the amount of barium and calcium was only one-half that of the sodium or potassium, giving $x = 1$; the formula $BaMn_8O_{16}$ corresponds on a valency basis to $K_2Mn_8O_{16}$.

Unpublished work by us has shown that α-MnO_2 containing potassium does not decompose until heated above 900° and is more readily formed from the δ-oxide; these results may be quite reasonably explained if in this case we follow Byström and Byström and associate one foreign ion with each unit cell. If all the available sites are thus occupied, corresponding to $x = 1$, the distance between neighbouring barium ions is only 2·85 Å. As the ionic diameter of Ba^{++} is 2·76 Å it would follow that strong repulsive forces must occur between the doubly charged ions leading to structural instability and the decomposition of the oxide at temperatures of the order of 580°.

In accepting the Byström picture for the barium compound whilst rejecting the full implication (a maximum of one foreign cation per unit cell) for the sodium and potassium compounds, we may appear inconsistent but the behaviour of the two groups of preparations is strikingly different. It should be remembered that Byström and Byström carried out a full structural analysis on hollandite only (A = Ba^{++}) and since Gruner (*Amer. Mineralogist*, 1943, **28**, 497) had shown the mineral to be isostructural with corondite and cryptomelane they applied their findings to the latter pair of minerals as well. Since the ionic diameters of Ba^{++}, Pb^{++}, and K^+ are very close this seems to be justifiable, although it would be reasonable to expect that a marked difference in chemical behaviour might follow by the interchange of doubly and singly charged ions.

The problem of the conversion of the δ- into the α-phase and the concurrent stability of the latter was examined by the experiments embodied in Preparations **7** and **9**. It was considered that if part of the barium or calcium could be removed from the material so that all available sites were no longer occupied, the conversion into α-MnO_2 might take place readily without decomposition. The precipitates were therefore leached with 4N-nitric acid for four hours, washed, and dried at 120°. *X*-Ray diffraction showed that this treatment was sufficient to convert both preparations into α-MnO_2 with a crystallinity at least as good as that of the best crystallised potassium-containing preparations. A slight further improvement in crystallinity followed on heating to 400°. The value of x in the general formula was reduced to about 0·1 and this would render unnecessary any short barium- or calcium-ion distances in the α-MnO_2. It is considered that these experiments are strong confirmation of our ideas concerning the difficulty of obtaining α-MnO_2 from Preparations **6** and **8**.

Electrochemical Properties.—The values of $E°$, relative to the hydrogen electrode, calculated from the e.m.f. of the individual electrodes show, for each preparation, a good agreement among themselves and the general assumption that the cell reaction is the same for these cells as for that containing β-MnO_2. The results will be discussed in groups according to the structures.

The two samples of γ-MnO_2 prepared by chemical oxidation [**1**(*a*) and **3**(*a*)] had a practically identical e.m.f. in spite of the somewhat different methods of preparation and the presence of potassium in **3**(*a*). The value was *ca.* 30—35 mv above the value for the cell containing β-MnO_2 and was decreased by 5 mv when the oxide was heated to 200° to give **1**(*e*). The γ-MnO_2 formed by electrolytic deposition at the anode (Preparation **11**) had a value very close to this, being nearly 40 mv positive to that of β-MnO_2. The commercial electrolytic preparations all had values in the range 30—35 mv above

that of β-MnO_2 although the scatter of 5 mv over all the samples shows that different conditions of formation influence the potential to a small extent.

No correlation was observed between e.m.f. and available oxygen although Preparation 11 which had the highest value of n (in formula MnO_n) also showed the highest e.m.f. Boiling with nitric acid had the effect of bringing their formulæ together but the values for the e.m.f. did not approach one another. The active oxygen content increased to the value $n = 1{\cdot}97$ but the values for the e.m.f. all showed a decrease which varied for the different preparations, some being affected considerably [13(*a*)] whilst with others [13(*c*)] the e.m.f. was reduced hardly at all.

The γ-oxide produced by chemical oxidation has an e.m.f. which fluctuates more than that produced electrolytically. These fluctuations are about ±1 mv from the final equilibrium value and appear to be quite random, no definite trend being observed. This was not the case with the electrolytic oxides, which, on attaining their final value, remained extremely constant for as long as measurements were continued, even though individual electrodes from the same sample showed slight differences from one another. When the electrolytic preparations were boiled with nitric acid the cells made up from them showed precisely the same fluctuations as those observed with the chemically prepared γ-MnO_2. Thus the electrolytic γ-MnO_2 would appear to have some property which is particularly desirable in an electrochemical system.

The well-crystallised samples of α-MnO_2 [4(*h*), 5(*h*), and 10(*h*)] all had an e.m.f. more than 30 mv greater than the cell containing β-MnO_2, practically the same value as that containing γ-MnO_2. This is not surprising since the structures of the α-MnO_2 minerals and ramsdellite are built up from the double strings of octahedra and differ only in the method of linking, so it would be expected that both structures would have approximately the same free energies of formation. The mixed phases of α- and γ-MnO_2 produced in Preparations 1 and 2 were all about 40—45 mv above the β-MnO_2 potential; this was reduced by some 10 mv after the oxides were annealed at 200° and by a further 5 mv after heating to 400° when α-MnO_2 was the only phase present [1(*g*)]. This last value is the same as that observed for the α-MnO_2 in 4(*h*), 5(*h*), and 10(*h*) so that the nature of the foreign ion in the structure appears to play no part in determining the e.m.f. when the oxide is well crystallised.

This point may be illustrated by a consideration of Table 2 in which the method of preparation, formulæ, and electrode potential of six different specimens of α-MnO_2 containing in all five different foreign cations are listed.

TABLE 2.

Method of prep.	Nature of oxide	$E°$ (v)
Oxidation of acidified $MnSO_4$ by $(NH_4)_2S_2O_8$	γ ⟶ α by heating at 400° in O_2. $(NH_4)_{0\cdot02}MnO_{1\cdot98}$	1·252
HCl added to boiling $NaMnO_4$	δ ⟶ α by heating at 500° in O_2. $Na_{0\cdot22}MnO_{1\cdot99}$	1·250
HCl added to boiling $KMnO_4$	δ ⟶ α by heating at 500° in O_2. $K_{0\cdot27}MnO_{1\cdot68}$	1·252
HCl added to boiling $Ba(MnO_4)_2$	δ ⟶ α by boiling with 4N-HNO_3 drying at 120° and heating at 400° in O_2. $Ba_{0\cdot02}MnO_{1\cdot98}$	1·252
HCl added to boiling $Ca(MnO_4)_2$	δ ⟶ α by boiling with 4N-HNO_3 drying at 120° and heating at 400° in O_2. $Ca_{0\cdot01}MnO_{1\cdot98}$	1·258
B.D.H. Sample	δ ⟶ α by heating at 400° in O_2. $K_{0\cdot21}MnO_{1\cdot90}$	1·252

The two oxides, the second and fifth oxide in Table 2, which gave e.m.f.'s differing slightly from 1·252 volts differed also in other properties; the former did not show the usual straw-like shape of α-MnO_2 but occurred as a fairly uniform material without elongation in any particular direction; the latter was still a rather poorly crystallised material.

The potential of the α-MnO_2 corresponded to a molar free energy of formation of about 680 cal. less than for β-MnO_2; it is important to note that it has a more open structure.

The results of Preparation 3 illustrate the change in the potential of the oxides as the composition changes from nearly pure γ-MnO_2 to the nearly pure α-phase. As the amount of the α-oxide increases the potential rises steadily and with the last-formed portion of the precipitate the e.m.f. is 30 mv greater than that from the first precipitated material. Even though 3(*c*) shows the typical α-MnO_2 *X*-ray pattern the e.m.f. of this cell is 30 mv greater than the cells containing 4(*h*) and 10(*h*). It follows that this form of the oxide may have

large variations in an estimate of the free energy of formation calculated from differences in the e.m.f.

The e.m.f.'s of the cells containing δ-MnO_2 were about 50 mv greater than for β-MnO_2 in the case of the oxides precipitated from potassium and sodium permanganates. Oxides formed from barium and calcium permanganates were approximately 60 and 70 mv respectively above the β-MnO_2 potential. With all these preparations it was extremely difficult to obtain steady potentials. Repeated grinding and prolonged soaking with the electrolyte were necessary before even moderately stable results were obtained and even then readings could not be made in the two solutions where the acid concentration was lowest (p. 4059). After measuring the e.m.f. in the three most acid solutions a further attempt was made to measure these oxides in the two less acid solutions. However, their behaviour was exactly the same as before and satisfactory values were only obtained for the three solutions of highest acid concentration.

The oxides obtained by heating the δ-MnO_2 showed an interesting effect; the e.m.f. of the cells made up from them all rose steadily as the temperature of annealing increased. Preparations 4, 5, and 10 all behaved similarly, the potential increasing as the sintering temperature increased and reaching a maximum value for the oxides heated at 275° and 300°. The potentials of the oxides heated in this range were about 65—75 mv above that of β-MnO_2. These are the oxides in which sufficient α-MnO_2 had been formed for it to be detectable by *X*-ray diffraction. Heating at higher temperatures resulted in a marked decline in the e.m.f.; the value for the oxides heated at 400° had dropped to 50—60 mv above that for β-MnO_2 while for those heated to 500° it was about 30 mv positive to the standard. With all these sintered preparations it was again found impossible to obtain readings in the solutions of lowest acid concentration and their behaviour was the same as that of δ-MnO_2 as precipitated. With the oxides heated at 400° and 500° it was possible, after prolonged soaking of the oxide, to measure the e.m.f. in cells containing the electrolyte 0·03 M in hydrochloric acid.

The preparations of δ-MnO_2 containing Ba^{++} and Ca^{++} (6 and 7) were similar to one another in their behaviour on being heated. As precipitated, they were respectively 60 and 70 mv positive to β-MnO_2 and on heating to 200° the values of the e.m.f. were about 80 mv above that of our standard. The oxides heated to 400° did not give a steady e.m.f. in any of the five electrolytes. However, the mean value seemed to be even higher than those of the oxides heated to 200° although subject to oscillations of about ±7—8 mv.

After most of the Ba^{++} and Ca^{++} had been removed by boiling with nitric acid [7(*a*) and 9(*a*)] the oxides were found to have the α-MnO_2 structure and the e.m.f. had dropped to 40 mv above that of β-MnO_2. It was reduced by a further 10 mv after heating at 400° when the value 30 mv positive to our standard was found. To explain the e.m.f. results in the δ-MnO_2 → α-MnO_2 transition, the rise to a maximum value and the subsequent decline following the formation of α-MnO_2 as the temperature of sintering was increased must be accounted for. δ-MnO_2, as precipitated, had almost the theoretically required amount of available oxygen for the formula MnO_2. On sintering, this available oxygen decreased, owing to the entry of the foreign-metal ions into lattice positions. If δ-MnO_2 has a poorly crystalline and distorted α-MnO_2 arrangement, the process can be pictured as follows. During the heating the large ions pass continuously into positions in the tunnels in the structure. The double strings of octahedra are probably "staggered" and not oriented exactly parallel to one another. This continuous pasage of the foreign ions into the oxide leads to a gradual change in the structure up to a point where the disordered arrangement becomes unstable with respect to the more regular α-MnO_2 system at the temperature of heating and an ordering process takes place. The results from electron microscopy suggest that the formation of α-MnO_2 takes place at certain nuclei which then grow throughout the bulk of the oxide.

The breadth of the lines of the *X*-ray diffraction photographs indicates that the crystallite size in the δ-MnO_2 preparations is extremely small and surface free energy must play some part in determining the e.m.f. of the cells containing these oxides. The surface free energy is unlikely to increase on sintering so that our explanation of the rise in the e.m.f. on heating is still valid. When the α-MnO_2 is first formed the needle-shaped

crystallites are poorly developed and even the oxides heated at 400° showed some broadening of the *X*-ray diffraction lines. The decrease in the e.m.f. observed after the formation of α-MnO_2 for the oxides heated at 400° and 590° is probably due to the removal of lattice defects and the decrease in surface free energy as the crystallites develop in size and regularity. This decrease is probably taking place continuously over the whole sintering range but in the lower temperature region its effect is masked by the process of the entry of the foreign-metal ions into the structure.

Reference will finally be made to an effect which was noticed with δ-MnO_2 and many of the α-MnO_2 preparations, particularly 4, 5, and 10. After the electrolyte had been introduced and the cell set up, a steady fall in the measured e.m.f. was observed; this continued for as long as readings were taken, in some cases for as long as two weeks. When the electrolyte was renewed, with as little disturbance of the MnO_2 slurry as possible, the e.m.f. returned to within 1 mv of the original value and then started to fall as before; this occurred each time the electrolyte was changed. To obtain an e.m.f. of use as a comparison with other preparations it was necessary to standardise the method of measurement. After renewal of the electrolyte for the second time the cell was left for twelve hours to settle down. Readings were then made during the next six hours and as these were constant to about 1 mv they were taken as the e.m.f. of the cell and are the values used to calculate the values of E° given in Table 1.

The rate of the decrease in the e.m.f. varied considerably, being 2—3 mv per day in the case of δ-MnO_2 heated in the temperature range 200—300° and less than 1 mv per day for the α-MnO_2 preparations heated to 400° and 500°. It might be argued that disturbing the electrode caused the e.m.f. to rise, as happens with powder electrodes, and we were only observing the subsequent decline. However, this effect was not observed with γ-MnO_2 preparations which were subjected to identical treatment or with the mixed α and γ phases produced in Preparations 1 and 2. Also, all the cells were left for twelve hours before measurements were taken and it would be expected that the electrode had by then settled down. It is concluded that some spontaneous reaction is occurring between the electrode and the electrolyte. In view of the inability to obtain e.m.f. readings for the same preparations in solutions of low acid concentration it seems likely that this reaction involves the hydrochloric acid.

Reference was made in an earlier paper (Butler and Thirsk, *J. Electrochem. Soc.*, 1953, **100**, 297), to the possible existence of lower oxides, particularly MnO, as surface layers in the majority of preparations involving precipitation from solution. With δ-MnO_2 electron diffraction revealed only the presence of MnO and Mn_3O_4 and it is these oxides which show the most rapid fall in e.m.f. with time. An explanation of the decreasing e.m.f. is therefore that it is due to the dissolution of a lower oxide in the acid electrolyte. This would produce an increase in the concentration of manganous chloride and an accompanying decrease in the hydrochloric acid. As the change in e.m.f. with concentration is governed by the ratio of the activities of manganous chloride and hydrochloric acid the relative effect of these interdependent concentration changes would be large. The idea also accounts successfully for the e.m.f.'s returning to its original value on renewal of the electrolyte and provides further evidence for the existence of lower surface oxides, in particular in the cases where they had been observed by electron diffraction.

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Adsorption of Insoluble Vapours on Water Surfaces. Part I.

By C. L. Cutting and D. C. Jones.

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A study of the surface concentrations on a water surface of a number of pure substances, almost insoluble in the liquid phase, but whose vapour pressures can be measured, has been made. The change in surface tension as the vapour pressure increases up to the saturation pressure has been measured, and the Gibbs adsorption equation used to calculate the adsorption excess. The isotherms so obtained have resemblances to, but also some differences from, Type III of Brunauer's classification. The films are gaseous, and the surface concentrations vary, even at the saturation pressure, from values corresponding to a fraction of a monolayer, to multilayers. Overall surface concentrations of less than monolayers occur in some systems which, nevertheless, obey Antonow's rule approximately. The films could be described in terms of the surface analogue to an equation of state such as that of van der Waals with the attraction term predominant, but it is suggested that unrestricted multilayer formation also occurs, and that the unusual results can be explained only by considering the life of the adsorbate on the bare liquid surface, as well as its life in the monolayer and in the multilayers, as affected by interaction with other adsorbate molecules.

The adsorption equation in a two-component system, and under isothermal conditions is

$$\Gamma_2^{(1)} = -\mathrm{d}\gamma/\mathrm{d}\mu_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where $\Gamma_2^{(1)}$ is the adsorption excess of component 2, when Γ_1, the adsorption excess of component 1, is zero. It is thus possible to calculate $\Gamma_2^{(1)}$ if the rate of change of surface tension (γ) with the chemical potential of component 2 (μ_2) is determined in a system in equilibrium. $\Gamma_2^{(1)}$ can also be calculated from measurements of the differences in the concentration, expressed per g. of solvent, of component 2, in the surface layer and in the bulk solution respectively (McBain and Swain, *Proc. Roy. Soc.*, 1936, *A*, **154**, 608). Earlier experiments have determined Γ_2 corresponding to other conventions (*e.g.*, Donnan and Barker, *ibid.*, 1911, *A*, **85**, 557) but, in the dilutions used, the adsorption-excess values are almost identical with those of $\Gamma_2^{(1)}$.

In using equation (1) directly for the determination of $\Gamma_2^{(1)}$ experiments are limited to liquid–liquid or liquid–vapour interfaces where changes in γ can be measured as μ_2 changes. In liquid–vapour interfaces there are four cases: (1) component 2 is practically non-volatile at the temperature of the experiment and its μ_2 must be determined in the liquid phase; (2) component 2 is sufficiently volatile so that its μ_2 can be determined either in the liquid, or in the vapour phase in equilibrium with the surface, *e.g.*, ethyl alcohol in water; (3) component 2 is volatile but so insoluble that its μ_2 can be determined only in the vapour phase, as in the experiments described here; (4) component 2 is insoluble and non-volatile and in Gibbs's words " when one of the components, however, is found only at the surface of discontinuity, it may be more easy to measure its superficial density (Γ) than its potential (μ) " (" Scientific Papers," Longmans, Green and Co., London, 1906, Vol. 1, 233). It can be readily shown that the quantity of component 2 present per cm.^{2} of interface is equal to $\Gamma_2^{(1)}$ if the Gibbs conventional surface is put in the physical interface in case 4 (above), and that the error involved in doing this for case 3 is usually negligible, so that in our experiments the surface concentration is almost identical with $\Gamma_2^{(1)}$, and can be determined by equation (1). If the deviations of the mixed vapours from Dalton's law can be neglected, and the vapour of the adsorbate assumed to obey ideal-gas laws, equation (1) can be written

$$\Gamma_2^{(1)} = -\frac{1}{RT}\left(\frac{\mathrm{d}\gamma}{\mathrm{d}\ln p_2}\right) \text{ or } -\frac{p_2}{RT}\frac{\mathrm{d}\gamma}{\mathrm{d}p_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

and thus $\Gamma_2^{(1)}$ values can be obtained from the tangents to carefully drawn large-scale log p_2–γ or p_2–γ curves: with experience this can be done with very fair accuracy.

In an experimental study of Antonow's rule (Carter and Jones, *Trans. Faraday Soc.*, 1934, **30**, 1027), it was suggested that an explanation of the agreement of some pairs of partially miscible liquids with this rule was essentially that given by Gibbs (*op. cit.*, p. 235) in a footnote referring to the system mercury–water vapour. Here Gibbs implicitly assumed Antonow's rule. It was decided to investigate the course of the adsorption on a water-vapour surface by examining the change of γ with the partial pressures of the vapour, of some of the substances whose agreement, or otherwise, with this rule seemed fairly well established. It should then be possible to determine, within the limits of precision of the method, whether, at saturation, the adsorbed layer could be considered as of sufficient thickness to possess the bulk properties of the liquid phase (see Ottewill and Jones, *Nature*, 1950, **166**, 687).

The determination of surface concentrations by this method has advantages over the analogous one where vapours are adsorbed on solid surfaces: the liquid surface can be cleaned or freshly produced, and it is reproducible; it is unnecessary to know the area of the adsorbent, which is usually an inexact measurement for solid surfaces; the difficult measurements necessary in experiments with small specific areas of solid surfaces, which must be used if the surfaces are to be plane, are replaced by the experimental work involved in the application of equation (2). This should be a good method for studying the occurrence, or not, of multilayers. The adsorbate vapour must not be too soluble, but the method is capable of extension in this respect.

Some earlier work on the adsorption of vapour on water surfaces has been reported by Micheli (*Phil. Mag.*, 1927, **3**, 895) and by Cassel and Formstecher (*Kolloid Z.*, 1932, **61**, 18). It soon became evident that our experiments led to results widely different from those of Micheli and considerably different from those of Cassel and Formstecher in the region of higher partial vapour pressure. These differences are confirmed by our experiments in which the vertical film balance is used, and which will be described in Part II.

In our experiments we bring the vapours of the adsorbate, at vapour pressures increasing up to the saturation pressure, into equilibrium with a clean surface of water, and measure the change in γ produced. It did not seem feasible to use an evacuated system, and the vapour was carried in a stream of air or nitrogen to the water surface. Sugden's adaptation of the maximum pressure in bubbles method (*J.*, 1922, **121**, 858), which is independent of contact angle, was used, and also the capillary-rise method as adapted by Ferguson and Hakes (*Proc. Phys. Soc.*, 1929, **41**, 414). The latter method is more accurate than Sugden's, and very convenient for our purpose, although it was necessary to show that the contact angles, with falling menisci, were sensibly zero. In either method each separate measurement was determined starting from a freshly formed bubble surface.

As expected with the adsorbates used, the adsorption process was very rapid and the results obtained by Sugden's dynamic method were in close agreement with those obtained by Ferguson and Hakes's static method.

Experimental

Fig. 1 illustrates the essential parts of the Ferguson and Hakes method as adapted to this work. The vessel *A*, which contained the adsorbate, was surrounded by a water-jacket whose temperature was indicated by the thermometer *T*, and was fed from a subsidiary thermostat. The water in *C* had a surface of *ca.* 6 cm. diameter, which was large in relation to the size of the capillary. It was possible to arrange the relative positions of the main thermostat and water-jacket so that, after saturating the air stream with adsorbate vapour at the chosen temperature of the jacket, the vapour stream could be passed directly to the main thermostat without being exposed to any fall of temperature, and corresponding reduction of vapour pressure. It is suggested that the much smaller surface-tension depressions usually observed by Micheli (*loc. cit.*) were due to a defect here in his experimental arrangements. Carter and Jones (*loc. cit.*) found quite erroneous results for γ for liquid water saturated with benzene, unless the vapour phase was kept saturated with benzene vapour.

The capillary tube was held vertical by an especially designed clamp which gripped the

saturator *B* and was adjustable in two vertical planes at right angles. The water meniscus was forced down to the bottom of the capillary by careful adjustments to the height of a water reservoir. In order to avoid bench and floor movements, the clamp was fixed on to heavy iron wall attachments. Room draughts had to be avoided. No lubricant was used on any joints, which were mercury-sealed where necessary. The experimental application of the Ferguson and Hakes method is much simplified if the capillary is immersed to a depth h', equal to $r/3$ where r is the inside capillary radius. The formula for γ then reduces to $1/2\ grdh$, where d is the density, and h is the height in cm. of the manometric liquid necessary to force down the meniscus until it is level with the bottom of the capillary. A travelling vernier microscope was focused on a mark etched on the capillary, lowered by $r/3$, and then the capillary lowered until the mark was again on the crosswire. The area of the liquid surface in *C* was large enough to make negligible the consequent small rise in the outer liquid level. We used either water, or alcohol coloured with magenta, in the manometer, and found the latter liquid very satisfactory; it was renewed from time to time from a main supply. The manometer was held vertically in a specially constructed brass clamp attached to the wall bracket. It was immersed in the main thermostat, and the levels read by a vernier microscope with an accuracy of *ca.* $\pm 0{\cdot}001$ cm. A water-manometer was used occasionally and proved quite satisfactory; it is less sensitive,

FIG. 1.

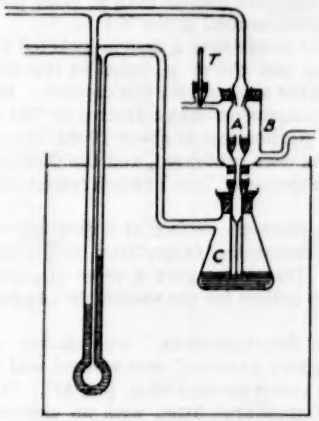
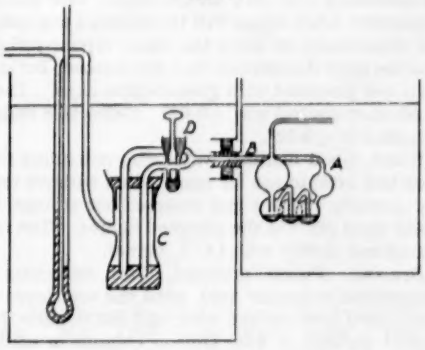


FIG. 2.



and if exposed to the London atmosphere has to be frequently renewed; it has, however, other obvious practical advantages. In this method the radius of the capillary needs only to be known at the tip, and the temperature control of the meniscus is much simplified. It was very convenient to have a static method where the adsorbing surface of the meniscus could be renewed at will by a slight increase of pressure in the apparatus.

The efficiency of the saturation was carefully tested; *e.g.*, the results were unchanged when the vapour space above the cup in the saturator *A* was packed with glass-wool soaked in the liquid adsorbate. In practice, we used a water-saturated solution of adsorbate instead of the adsorbate itself: with these sparingly soluble adsorbates, however, no difference in the results could be detected.

By appropriate adjustment of the reservoir, the surface could be merely renewed, with little vapour escaping through the liquid, or an entirely fresh supply of vapour could be drawn down from the saturator cup. If the stream of air was drawn too rapidly over the surface of the adsorbate, the temperature was lowered and the results were affected.

Fig. 2 illustrates our adaptation of Sugden's modification of Jaeger's method. The method is dynamic but the pressure increase could be controlled so as to give a very slow bubble expansion. It is also independent of contact angle and so was considered a desirable check on our other measurements. The adsorbate phase was contained in the saturator *A* in the subsidiary thermostat. Vapour was drawn through the glass connecting tube *B*, which passed through flanged openings in the sides of the tanks, to the maximum bubble pressure apparatus in the main thermostat. A plug of glass-wool separated the water in the two tanks. This provided another method of avoiding a fall of temperature between the thermostats and proved quite

satisfactory. The vessel *C*, containing the water adsorbent, had a diameter of *ca.* 4 cm., and the capillary tubes were immersed to *ca.* 1 cm. The mercury-sealed tap, *D*, on which no lubricant was used, served to cut off the vapour stream from the wider tube when measurements were being taken with the fine capillary. We followed the directions given by Mills and Robinson (*J.*, 1931, 1629) for the construction of the capillaries, including the use of quill tubing, although this proved to be rather a lengthy process. The apparatus was standardised by using both pure water and benzene.

The stopper of vessel *C* was unlubricated and mercury sealed. A mercury aspirator provided a sensitive method of drawing the vapour through the apparatus so that a slow bubble rate (*ca.* 1 bubble every 30 sec.) could be maintained.

Contact-angle Measurements.—Contact angles against the soda-glass capillaries were measured by Bartell and Merrill's method (*J. Phys. Chem.*, 1932, **36**, 1178) (see also Carter and Jones, *loc. cit.*). Photomicrographs were taken in a number of cases. In all cases the contact angle proved sensibly zero.

Thermostats.—The large thermostats were controlled to $\pm 0{\cdot}03°$ and were provided with plate-glass windows, of tested planarity, at back and front to allow for good illumination and observation. Accurate control of the temperature of the baths is particularly important when the measurements are being made at close to saturation, and the temperatures of the baths are very close to one another. The errors in this region are therefore greater than at other points. The thermometers were compared with an Anschütz set, standardised at the N.P.L.

Materials.—M. p.s were determined on about 15 ml. of material in a double-jacketed tube. The substance was very slowly cooled with good stirring, and the m. p. taken at the steady temperature when about half the material was solidified in the form of very fine crystals. B. p.s were determined by using the usual vapour-jacketing arrangements and corrected to 760 mm. Densities were determined in a two-limbed, Perkin type, pyknometer of about 10-ml. capacity, which was provided with ground-glass caps. The weights were calibrated, and the thermostat temperature control was $\pm 0{\cdot}02°$ Refractive indices were measured in a Pulfrich refractometer controlled to $\pm 0{\cdot}02°$.

Water. Good distilled water was redistilled from the block-tin surface of a Bousfield still, which had been in use for many years without repair or dismantling of any kind, and collected in a carefully cleaned and steamed-out storage bottle. This water gave a value of γ within $\pm$ 0·05 dyne cm.$^{-1}$ of the accepted figures. The refractive indices for the sodium and hydrogen lines agreed closely with I.C.T. values.

Benzene. Purest material, "for molecular weight determinations," was shaken with concentrated sulphuric acid, until the acid layer only slightly darkened, was washed well with water, dried over sodium wire, and fractionally frozen to give a product of m. p. 5·45°. It was distilled through a 4-ft. Dufton column in an all-glass apparatus fitted with an electrically heated air-jacket, and the middle fraction collected. This had m. p. 5·48°, b. p. 80·10°/760 mm., d_4^{25} 0·8732, n_D^{20} 1·5012.

Toluene. Kahlbaum's purest material was chemically treated as was benzene, and twice fractionally distilled through the Dufton column. The middle fraction was used and had b. p. 110·70°/760 mm., d_4^{25} 0·8614, n_D^{25} 1·4936.

p-*Xylene.* Kahlbaum's "purest" material, m. p. 12·8°, was fractionally frozen until a product of m. p. 13·23° was obtained. It was redistilled and the middle fraction used: it had d_4^{25} 0·8659, n_D^{25} 1·4932.

n-*Pentane.* Synthetic material was washed with several amounts of 25% oleum, with dilute aqueous sodium hydroxide, and with permanganate solution, dried (KOH), and fractionally distilled through the Dufton column: it had b. p. 35·9°/760 mm., d_4^{25} 0·6210, n_D^{25} 1·3546.

n-*Hexane.* This was prepared from pure *n*-propyl bromide and chemically treated as for *n*-pentane. It was fractionally distilled through the Dufton column, from sodium, and distilled over completely within 0·1°: it had b. p. 68·90°/760 mm., d_4^{25} 0·6556, n_D^{25} 1·3726.

n-*Heptane.* A synthetic material, treated in the same way as hexane, had b. p. 98·40°/760 mm., n_D^{25} 1·3854, d_4^{25} 0·6791.

n-*Octane.* An Eastman–Kodak synthetic material was similarly treated: it had b. p. 125·53°/760 mm., n_D^{25} 1·3953, d_4^{25} 0·6986.

n-*Decane.* A synthetic material from Malcolm Dyson was chemically treated as was hexane. It was fractionally distilled under 100 mm., then having b. p. 104·5°/100 mm., n_D^{25} 1·4102, d_4^{25} 0·7270.

n-*Tetradecane.* An Eastman-Kodak synthetic material was treated as for hexane and repeatedly fractionally crystallised. It was fractionally distilled under 5 mm. pressure, and the main fraction used; it had b. p. 107°/5 mm., d_4^{25} 0·7602.

cyclo*Hexane*. A Hopkin and Williams product, purified as suggested by Jones and Amstell (*J.*, 1930, 1316), had m. p. 6·45°, d_4^{25} 0·7737, b. p. 80·93°/760 mm.

Carbon tetrachloride. "AnalaR" material was shaken with silica gel, washed with water, dried ($CaCl_2$–K_2CO_3), and fractionally distilled through a 9′ column of the Clarke and Rahrs type (*J. Ind. Eng. Chem.*, **1923**, **15**, 349). A small middle fraction was used, having b. p. 76·71°/760 mm., n_D^{25} 1·4575, d_4^{25} 1·58442.

The physical properties of the adsorbates are in good agreement with available standard values except for *n*-hexane which has a slightly lower b. p. and density than those given by Forziati, Glasgow, Willingham, and Rossini (*J. Res. Nat. Bur. Stand.*, **1946**, **36**, 129).

Results and Discussion

In Fig. 3 are shown the γ–p curves at 25° for the normal saturated hydrocarbons from pentane to octane (full lines) and for carbon tetrachloride, benzene, and toluene (broken lines), which are typical for all the systems investigated. At low partial pressure of the vapour, the fall of tension is almost linear. Further equal partial-pressure increments

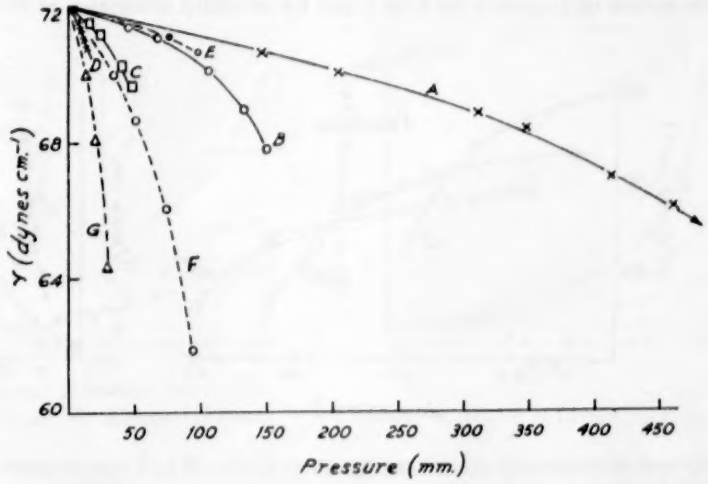


FIG. 3.
A, Pentane.
B, Hexane.
C, Heptane.
D, Octane.
E, Carbon tetrachloride.
F, Benzene.
G, Toluene.
Temp., 25°.

produce continually increasing effects on the depression of the surface tension, giving curves that are concave to the γ axis: $-d\gamma/dp$ increases continuously with increase of p. In almost all binary systems previously examined the corresponding curves are convex to the γ axis. Our results for the hydrocarbons are in this respect in disagreement with those of Micheli (*loc. cit.*) but in agreement with those of Cassel and Formstecher (*loc. cit.*). The instability found by the latter authors in the neighbourhood of saturation, we did not observe, and the γ depression, and therefore the adsorption at high values of partial pressures, was often considerably greater.

The group of curves for the saturated hydrocarbons show that, as the series is ascended, (1) at the same value of partial pressure the depression of tension *increases* rapidly, but that (2) at the final points on the curves, when $p = p_0$ (approx.), the depression of γ *decreases* markedly: (2) can be ascribed to the corresponding marked decrease of p_0 as the series is ascended. These trends continue with the still higher homologues, for qualitative experiments in the neighbourhood of saturation of *n*-decane gave a much smaller depression of γ than that for *n*-octane, and for water in contact with the saturated vapour of *n*-tetradecane, no change in γ could be detected. These results were confirmed by a direct determination of γ for the aqueous layer saturated with these hydrocarbons at 25°.

The curves for benzene and toluene, lying one on each side of the octane curve, show the much larger effects produced by these aromatic hydrocarbons, especially in the lowering

of γ at the final values of p (approx. p_0), toluene, as expected, having a smaller effect than benzene. The carbon tetrachloride curve, although the depressions are small, has the same typical concavity to the γ axis.

In Fig. 4 is shown an example of log p–γ curves for toluene vapour at three temperatures of the adsorbing surface. Graphs of this kind, drawn carefully on a large scale, were used to determine the $\Gamma_2^{(1)}$–p curves such as are exemplified for the case of toluene in Fig. 5. These curves are typical of the considerable number that have been investigated, and in Fig. 5 can be seen the relationships of the isotherms to one another as the temperature of the substrate surface increases. Compared at the same values of vapour pressure, the adsorption clearly increases with decrease of temperature, although the final $\Gamma_2^{(1)}$ values at the end points of the curve, approximately at p_0, are fairly similar. The calculations of the heats of adsorption for these systems will be given in a later paper.

In Fig. 6 are shown the adsorption isotherms for these saturated hydrocarbons on a water surface at 25° as calculated from the values shown in Fig. 3. All the isotherms are, throughout their *realisable* course, convex to the p-axis: $d\Gamma/dp$ continually increases with increase of p or of Γ. They do not approach a limiting value of Γ asymptotically as in the models of Langmuir for Case I and for restricted adsorption in the B.E.T. theory:

FIG. 4.

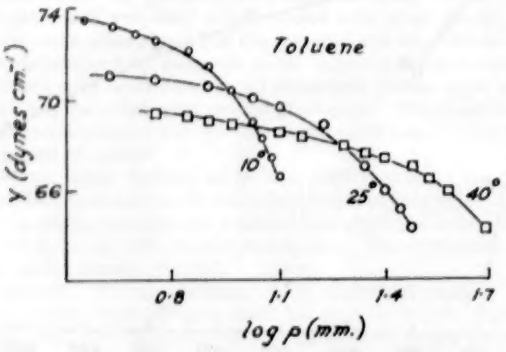
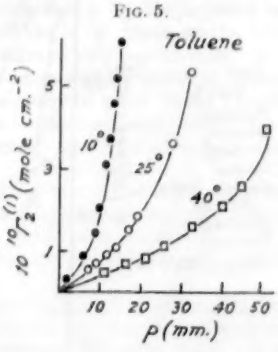


FIG. 5.



the isotherm equations are not asymptotic to a value of $p = p_0$ as in the case of unrestricted B.E.T. theory, *e.g.*, Type III, but they are, however, asymptotic to a value of $p > p_0$ in every case investigated. There is no evidence therefore, either from the experimentally determined points on the isotherm or from extrapolation of the empirical equations to the curves, that a limiting value of adsorption is being approached, even when the surface concentration is so extensive that, whatever molecular orientation is assumed, multilayers must be present.

From Fig. 6 it can be seen that for these four saturated hydrocarbons:

(*a*) When the adsorption can be compared at the same values of pressure it increases markedly as the homologous series is ascended. The small comparative differences introduced by using partial pressure values instead of collision numbers as abscissæ being neglected, this means that the life of the hydrocarbon molecules on the surface increases as the homologous series is ascended. At low surface coverages this is readily understood since the molecules would tend to lie flat on the surface. This observation is a qualitative statement of Traube's rule, applying here to molecules not possessing a water-soluble group with varying saturated hydrocarbon chains, but the varying chain itself. This effect is present, however, at all surface coverages, from conditions when only a small fraction of a monolayer is present even for octane, to conditions when the overall surface concentration is a monolayer or more, and in fact, it becomes progressively greater as the surface concentration of the compared hydrocarbons is increased.

(*b*) The adsorption at the saturation values, indicated in Fig. 6 *A*, *B*, *C*, and *D*, decreases

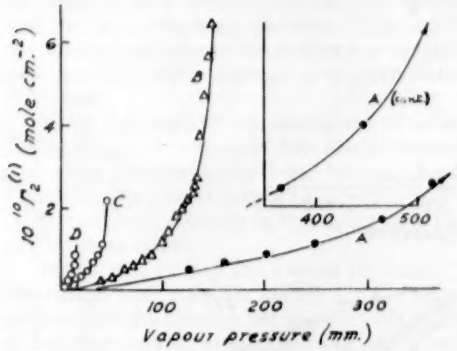
markedly as the series is ***descended***. This would appear to be caused by the increased life factor as the series is ascended being overpowered by the greatly increased values of the collision number, at $p = p_0$, as the series is descended (compare, *e.g.*, pentane $p_0^{25°} = 507$ mm.: octane $p_0^{25°} = 14$ mm.).

These two effects (*a*) and (*b*) above receive a ready qualitative explanation on using a simple collision mechanism for adsorption on a plane surface: effect (*b*) would be obscured normally when working with porous adsorbents or powders, owing to complications present in these systems at high values of p/p_0.

We cannot, of course, deduce directly from the small and negligible values, respectively, of the lowering of the tension at the saturation vapour pressure produced by *n*-decane and *n*-tetradecane, that the adsorptions of these substances at $p = p_0$ are correspondingly reduced below that of *n*-octane, since this is determined by the value of $d\gamma/d \log p$ at $p = p_0$, but, by analogy with the results shown in Fig. 6, it would seem probable.

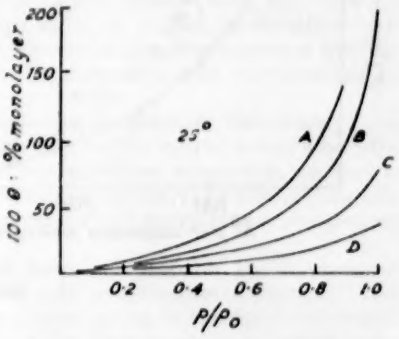
In Fig. 7, θ, the fraction of a monolayer, or $\Gamma_2^{(1)}/\Gamma_m$, where Γ_m is the adsorption corresponding to a completed monolayer, on the assumption of flat orientation, is plotted against p/p_0 for these hydrocarbons. As would be expected from the order of the adsorption at

FIG. 6.



A, Pentane B, Hexane. C, Heptane. D, Octane.

FIG. 7.



A, Pentane. B, Hexane. C, Heptane. D, Octane.

the saturation pressures (see Fig. 6), at all equal values of p/p_0 the values of θ are in the order pentane > hexane > heptane > octane, the explanation lying as before in the overpowering effect of the rapidly increasing values of p_0 as the series is ascended.

On the basis of a Langmuir case IV or VI, the latter being the B.E.T. model, the initial slopes of the curves in Fig. 6 $d\theta/dp$ ($p \rightarrow 0$) are equal to σ_1, the life of the various hydrocarbon molecules on the water surface, and these initial slopes are in the order octane > heptane > hexane > pentane. The initial slopes in Fig. 7, $d\theta/d(p/p_0)$ ($p/p_0 \rightarrow 0$) is equal to c or σ_1/σ_2, where σ_2 is the life of the hydrocarbon on its own liquid surface, and this, of course, rapidly increases with the length of the carbon chain. The initial slopes in Fig. 7 are in the reverse order to those in Fig. 6, and the values are approximately those expected on this theory. This reversal indicates that σ_1 increases as the chain lengthens at a slower rate than the corresponding increase of σ_2, or the life of an octane molecule is greater than that of a pentane molecule on a water surface, but the disparity in their lives on their own liquid surface is much greater. Undoubtedly the adsorption here is not of a localised mono- or multi-layer type, but the above explanation would apply to low adsorption coverage for a mobile film, and probably for higher surface concentrations as well.

Considering the adsorption values shown in Fig. 7, it will be seen that these experiments show conclusively that, unless some unheralded change in γ, when p is almost p_0, occurs, at $p/p_0 = 1$, the θ values range from 0·3 of a monolayer with octane, to a monolayer with heptane, and multilayers with pentane, orientations involving maximum area of contact with the adsorbent surface being assumed. Similar diversities have been found with the

other substances experimented with: *e.g.*, carbon tetrachloride $\theta^{25} = ca.\ 0{\cdot}7$; toluene $\theta^{25} = ca.\ 1{\cdot}0$.

These θ values, especially for the saturated hydrocarbons, change with the orientations assumed, but it appears established for these systems that, where values of a monolayer or over are obtained, they conform approximately to Antonow's rule: the hydrocarbons pentane to heptane illustrate this. Octane is the first in the saturated hydrocarbon series to deviate somewhat from the relation, and the deviation increases considerably for *n*-decane, where θ is probably very small, and still further for *n*-tetradecane, where θ is probably

FIG. 8.

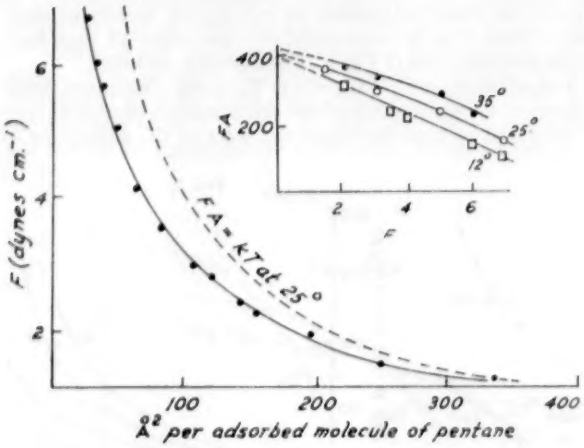
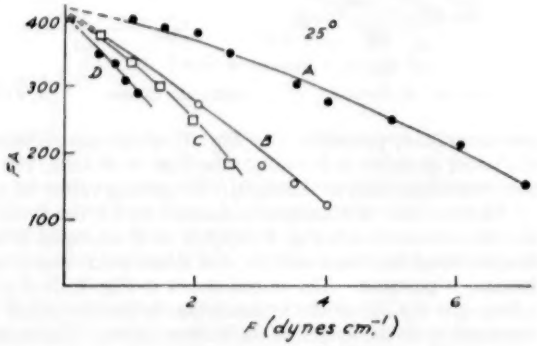


FIG. 9.
A, Pentane.
B, Hexane.
C, Heptane.
D, Octane.



negligible. Toluene conforms approximately and so does carbon tetrachloride, although θ in this case is less than a monolayer. It is possible that these gaseous films have approximately the surface properties of the bulk liquid even when the surface concentration is an incomplete monolayer (see Volmer, *Z. phys. Chem.*, 1925, **115**, 253). Further work may confirm, however, that deviation from this relation would always follow when θ, for gaseous films, becomes too small a fraction of a monolayer.

Fig. 8 is typical of the surface pressure–area (F/A) relations found for all the systems investigated. The curve that would be obtained at the same temperature for an ideal gaseous adsorbed film is also shown. It is seen that there is an increasing deviation from the ideal conditions which are found approximately at large A values; as A diminishes (Γ increases) for a given value of surface pressure, F, the A value found is always less than the ideal

one—the film appears more compressed—and this effect increases continuously up to the highest value found, *i.e.*, at the saturation vapour pressure, p_0, of the adsorbate; the films therefore could be described as gaseous, with considerable corrections, the attractive correction term always predominating.

These deviations from the ideal-gas conditions are seen perhaps more clearly in Fig. 9, where, for the four saturated hydrocarbons, the FA values are seen to fall increasingly below the ideal value as F increases. With some other vapours there seems to be evidence that the initial fall in FA is followed by a flattening of the curve, but no evidence is found, in any case, of a subsequent rise, much less of an attainment of a value of FA corresponding again to an ideal state of balance between the attraction and repulsion factors in the undoubtedly gaseous films formed by the ethyl esters of certain dicarboxylic acids (Adam and Jessop, *Proc. Roy. Soc.*, **1926**, *A*, **112**, 376). Even when the films are so concentrated that the overall values of Γ approach or even exceed monolayers, as in many cases they do, the attractive effects remain predominant. The effect due to increasing mutual attraction of the longer hydrocarbon chains in the steeply oriented films formed on water by the higher members of the acetic acid series is familiar, but the effect is observed in our experiments with such molecules as carbon tetrachloride, heptane, and benzene. In Kemball and Rideal's experiments (*Proc. Roy. Soc.*, 1946, *A*, **187**, 53) the same vapours, *e.g.*, heptane, adsorbed on to a mercury surface give isotherms of a quite different kind, *viz.*, Type II, and the films, which are gaseous, follow the Volmer equation, so that the deviation from the surface analogue to the perfect-gas equation is opposite in character to ours in that the area per molecule is always, at a given value of F, greater than that corresponding to $FA = kT$.

If we consider F as analogous to a surface osmotic pressure, the character of the deviation of a gaseous film should depend not only on the interaction of adsorbate molecules between themselves, but on the adsorbate–adsorbent interaction, so that a variation with substrate is to be expected just as the osmotic pressure of a solution depends on the solvent, although in this latter case the solvent–solvent interaction is also present and very important.

In the case of heptane vapour in contact with water it is probably the water–water interaction that accounts mainly for the very small bulk mole-fraction of heptane. The surface mole-fraction in our experiments is much greater, owing to the non-involvement of the water–water interaction, but the smallness of the heptane–water attraction compared with the heptane–heptane one accounts for the type of deviation from an ideal surface film which we found: the heptane–mercury attraction is, no doubt, much greater.

From the dynamic Langmuir–B.E.T. viewpoint the type of isotherm obtained (see Jones *et al.*, *J.*, **1951**, **126**, **1127**, **1464**) depends on (*a*) σ_1/σ_2 or c, where σ_2 could also be the life of a heptane molecule contiguous to another in the monolayer as envisaged in Langmuir's case IV, and on (*b*) layer restriction as, *e.g.*, in the films of the higher aliphatic acids on water. For our substrates the high overall $\Gamma_2^{(1)}$ values in some cases, and the isotherm shape, show that this restriction is not present. It would be erroneous to consider that this was a two-dimensional film in which ordinary heptane molecules were interacting only with each other as in the vapour phase, the water surface acting merely to " anchor " the adsorbed molecules temporarily to the surface.

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*Adsorption of Insoluble Vapours on Water Surfaces. Part II.**

By D. C. Jones and R. H. Ottewill.

[Reprint Order No. 6488.]

The vertical film balance method has been adapted to determine the surface pressure–vapour pressure relations of some saturated aliphatic hydrocarbons on a water surface at the temperatures 0°, 7·5°, and 15°; the corresponding adsorption isotherms were calculated from the Gibbs equation. It has been found that the isotherms all fit fairly closely an equation to a rectangular hyperbola of the type $\Gamma_2^{(1)} = Bp/(1 - k_1p)$, which, passing through the origin, is convex to the vapour-pressure axis: they are, however, asymptotic to a value of p which is greater than p_0, and so cut the line $p = p_0$. These systems have, therefore, finite values of $\Gamma_2^{(1)}$ at saturation (or very near to it). The F–p curves all fit the equation

$$F = -(2{\cdot}303BRT/k_1)\log_{10}(1 - k_1p)$$

which is formally similar to that of Szyszkowski (*Z. phys. Chem.*, 1908, **64**, 385), but with corresponding changes of sign. Values of the thermodynamic quantities ΔG, ΔH, and ΔS have been computed: all the ΔH values are smaller than the corresponding heats of liquefaction, and the entropy values are consistent with the view that mobile gaseous adsorption films are produced. The ΔG values for the series of normal saturated aliphatic hydrocarbons C_5 to C_8 give an increase of *ca.* 420 calories per carbon atom: this is a quantitative statement of Traube's rule applied to the saturated aliphatic hydrocarbons themselves.

The experimental methods described in Part I * had the advantage of providing a fresh surface of the adsorbent for each determination of the lowering of surface tension, F $(= \gamma_0 - \gamma)$, γ_0 being the surface tension of the pure solvent, and one of these methods was independent of the contact angle (if any). Owing mainly, however, to the small values of F in these systems the further development of the problem needed a more sensitive method for their determination; *e.g.*, the maximum depression of the surface tension of water by *n*-heptane at 25° is *ca.* 2 dynes cm.$^{-1}$, whereas values of 45 dynes cm.$^{-1}$ occur on mercury surfaces at this temperature. After considerable experimentation the vertical-film balance was adapted, and gave a more precise means of determining F, especially at low surface pressures. The method is static but dependent on contact angle: this proved to be sensibly zero if used with a falling meniscus, *i.e.*, the partially immersed plate was continuously withdrawn from the surface as the vapour pressure of the adsorbate increased.

Experimental

Materials.—Some physical properties of each substance used were determined. B. p.s were observed in an apparatus similar to that described by Jones and Betts (*J.*, 1928, 1177); densities were determined in a two-limbed Sprengel-type pyknometer of 10 ml. capacity, and refractive indices by a Pulfrich refractometer for the sodium-*D* line.

Water. Many experiments were carried out with good conductivity water from a Bousfield still: subsequently it was found that the central supply of distilled water to the College had a surface tension equally as good, *viz.*, γ^{20} 72·79 dynes cm.$^{-1}$ (Harkins and Brown, *J. Amer. Chem. Soc.*, 1919, **41**, 499, give γ^{20} 72·8 dynes cm.$^{-1}$). It was drawn directly from the bottom of a large earthenware container and used in most experiments.

Hydrocarbons. *n*-Pentane, *n*-hexane, *n*-heptane, and *iso*octane (2 : 2 : 4-trimethylpentane) were supplied by the Anglo-Iranian Oil Company, Ltd., as 99·5% pure material. All were stored over phosphoric oxide, and then fractionated through a 3-ft. Towers column packed with glass helices; the middle half was used. Synthetic *n*-octane (B.D.H.) was treated with several portions of 25% oleum during two weeks, washed with dilute aqueous sodium hydroxide, and alkaline and acid permanganate, and dried (P_2O_5). The product was fractionated through a 12-in. column packed with glass helices, and the middle third was collected for use.

* Part I, preceding paper.

The physical properties were in good agreement with those reported by Forziati, Glasgow, Willingham, and Rossini (*J. Res. Nat. Bur. Stand.*, 1946, **36**, 129, Research Paper No. 1695) (see Table 1).

TABLE 1. *Physical constants of aliphatic hydrocarbons.*

	n_D^{20}	n_D^{20} (N.B.S.)	B. p./760 mm. (± 0·05°)	B. p./760 mm. (N.B.S.)	d_4^{25}	d_4^{25} (N.B.S.)
n-Pentane	1·3576	1·35745	35·95°	36·073°	0·6208	—
n-Hexane	1·3749	1·37486	68·90	68·740	0·6550	0·65481
n-Heptane	1·3875	1·38764	98·30	98·426	0·6796	0·67949
n-Octane	1·3974	1·39743	125·60	125·665	0·6987	0·69849
2 : 2 : 4-Trimethylpentane	1·3914	1·39145	99·15	99·238	0·6877	0·68777

Vapour Pressures.—**n-*Pentane.*** These were calculated from equation (1) with the values $A = 27·691$ and $B = 7·558$ (I.C.T.) :

$$\log_{10} p_{\text{mm.}} = -(0·05223/T)A + B \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

n-*Hexane.* These were calculated similarly, with the values $A = 35·162$, $B = 8·399$ from $-20°$ to $-10°$, and $A = 31·679$, $B = 7·724$ from $-10°$ to $+15°$ (I.C.T.).

n-*Heptane and* n-*octane.* Values were interpolated from a $\log_{10} p_{\text{mm.}}$ against $1/T$ graph (I.C.T.)

2 : 2 : 4-*Trimethylpentane.* Values were interpolated from a $\log_{10} p_{\text{mm.}}$ against $1/T$ graph from the values given by Stull (*Ind. Eng. Chem.*, 1947, **39**, 517).

The Vertical-film Balance.—This has been used in conjunction with (*a*) an analytical balance and (*b*) a torsion balance. The analytical balance was a Sartorius beam balance with a sensitivity of two divisions per mg., modified so that the plate suspension, an aluminium rod, could be hung, together with a counterpoise (W) (see Fig. 1), in place of one balance pan. A mirror of 100 cm. radius of curvature was fixed at the mid-point of the top of the beam, and was used with a galvanometer lamp and scale. The balance was mounted on a rigid platform screwed to the top of the thermostat (T_1) containing the adsorption vessel. The torsion balance was made here and employed a phosphor-bronze torsion wire 12 cm. long, 0·012 cm. in diameter, firmly soldered into chucks at each end, one of which could be rotated through 180°. A small aluminium arm at the centre point of the wire carried a galvanometer mirror of 100 cm. radius of curvature. At one end of the arm was a small hook for attaching the plate suspension, and at the other, a small plunger, dipping into a well, allowed oil damping to be applied when required.

(a) *The analytical balance method.* The surface pressure is given in this case by the expression

$$F = k\Delta P/2(t + w) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

(see Harkins and Anderson, *J. Amer. Chem. Soc.*, 1937, **59**, 2189) where ΔP is the scale deflection, t the thickness of the plate, w the width of the plate, and k a constant which can be measured experimentally. The values of F obtained by this method are independent of any inaccuracies in the balance construction, since these are covered by k. However, k includes a density term and must therefore be measured at each temperature.

For a pure liquid at constant temperature, it may be shown that $k = g\Delta W/\Delta P$. In order to determine k, the plate is suspended in the liquid adsorbent, at the correct temperature, and the balance equilibrated. By further successive increments in weight, ΔW, a graph of ΔW against ΔP can be obtained over the range of ΔP required, and k obtained from the slope.

(b) *The torsion balance method.* It has been shown by Addison and Hutchinson (*J.*, 1948, 930) that

$$F = K_1\Delta P + K_2\Delta\phi \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where $\Delta\phi$ is the decrease of torque; $K_1[= (g_c t w l)/4(t + w)L]$ and $K_2[= 1/2(t + w)]$ are constants for the apparatus and a given plate, L being the distance between the mirror on the balance and the scale, and l the distance from the centre of the torsion wire to the point of suspension of the plate. Since the torsion wire is fixed at both ends, the torque depends only on the vertical movement of the plate, which was measured by means of the attached mirror, lamp, and scale. The wire was so arranged that lifting of the plate involved a decrease of torsion.

For calibration, a small pan was suspended from the arm; weights were added to this in small increments of *ca.* 5 mg., and the corresponding scale deflections, ΔP, read. The weights

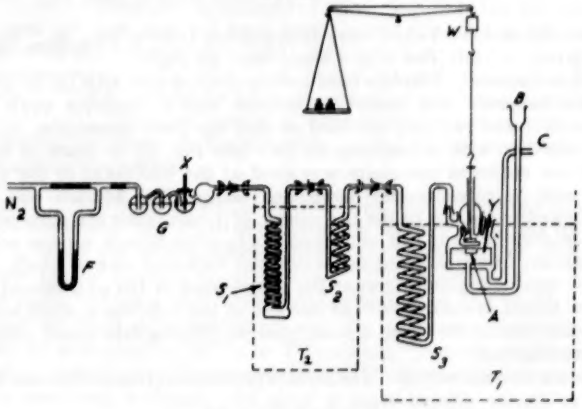
were then removed carefully, in small increments, and the ΔP values again obtained. The wire was replaced if any hysteresis was found. The relation between $\Delta\phi$ and ΔP was linear over the range used, and therefore, $\Delta\phi$ being put equal to $K_3\Delta P$, equation (3) may be written

$$F = (K_1 + K_2K_3)\Delta P \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

To calculate K_1, the distances l and L have to be measured mechanically; the analytical balance method was, therefore, preferred, although the torsion balance method was used extensively later.

Contact Angle.—It is essential when using the vertical-film balance that zero contact angle should be obtained and maintained. This was accomplished by keeping the plate completely immersed in distilled water and attaching the plate whilst still wet. After a few minutes in the surface the excess of water drained from the top of the plate and zero contact angle was obtained. It was usual, after the balance had reached equilibrium in the clean surface, to allow the plate to drain, otherwise a slight drift in readings was observed (see also Addison and Hutchinson, *loc. cit.*). Since in the adsorption experiments the surface tension always decreased, the plate rose out of the surface and zero contact angle was maintained.

FIG. 1.



Cleaning of Plates.—The glass plates were heated in chromic acid until it boiled gently, thoroughly rinsed, boiled, and again rinsed, all in distilled water, and then kept completely immersed in it until immediately before use.

Adsorption Apparatus.—This is illustrated in Fig. 1. A stream of nitrogen from a cylinder was washed, dried ($CaCl_2$) to prevent accumulation of water in the organic phase in the bubbler, and passed through the flow-meter (F) into the bubbler (G) where it became saturated with adsorbate vapour at room temperature or higher. The gas stream then passed through the spirals S_1 and S_2 contained in a large Dewar flask (T_2), used as a variable thermostat, where excess of vapour was condensed out (the experiments were below room temperature) so that the nitrogen stream, passing through spiral S_3 and into the adsorption vessel, A, contained a partial pressure of vapour corresponding to the temperature of T_2. As the vapour passed into the adsorption vessel, the surface tension changed slowly until equilibrium was reached for that partial pressure. Spiral S_2 was used merely to test whether effective condensation had occurred in S_1. This was checked at the end of each experiment, but no condensate was ever found in this spiral. Spiral S_3 was used to bring the vapour to the temperature of the adsorbent. Whilst this work was in progress (see Ottewill and Jones, *Nature*, 1950, **166**, 687), Dean and Hayes (*J. Amer. Chem. Soc.*, **1951**, **73**, 5583) independently developed a similar apparatus for measuring the sorption of vapours on monolayers.

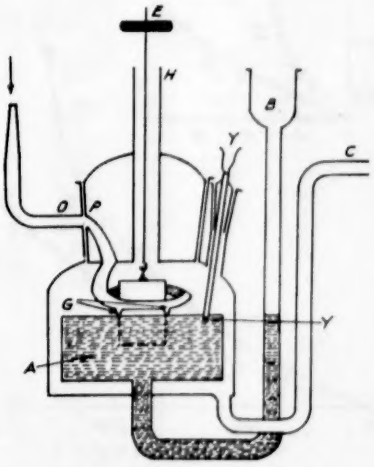
The adsorption experiments were carried out at several degrees below room temperature, to avoid condensation of the adsorbate vapour before it reached the adsorption vessel, in a small room with close-fitting windows and door, since good results by this method are only obtained if draughts and mechanical disturbances are absent.

X and *Y* (Fig. 1) were thermistors (type 1512/300, Standard Telephones and Cables, Ltd.); *Y* recorded the temperature of the adsorbent surface, *X* that of the last bulb in the bubbler, since evaporation sometimes lowered the temperature here. Adjustment was made if the temperature difference between this and the adsorbent surface became less than 5°.

The essential details of the adsorption vessel are shown in Fig. 2. Down the centre of stopper is the tube, *H*, for the plate suspension; the orifice (*P*) connects with the inlet in the socket (*O*). Vapour entering passed through the stopper to the four uniform jets, *G*. They were about 3 mm. above the liquid level in the trough, a distance at which no disturbance of the surface was caused at the flow rates used, and good contact between vapour and surface was obtained. The water was contained in trough *A*, which enabled a clean surface to be formed by overflowing from *B* (see Harkins and Jordan, *J. Amer. Chem. Soc.*, 1930, **52**, 1751), excess being drawn off *via C*. The vessel itself was mounted on a rigid stand, which could be adjusted in both horizontal and vertical planes, to ensure that the trough was horizontal, and the suspension tube vertical.

The Dewar thermostat, consisting of a 5-l. Dewar flask, was controlled to 0·01°. Alcohol was normally used as the bath liquid, cooled when necessary to low temperatures by the addition

FIG. 2.



of powdered "Drikold" and well stirred. Blank experiments, with water as the bath liquid, showed that the use of alcohol had no effect on the adsorption experiments. Near saturation the bath temperature could be easily increased in steps of 0·1° by a fine screw adjustment of the regulator. Temperatures were read on a −40° to +15° thermometer graduated in 0·1°, readable to 0·02°, which had been calibrated against an N.P.L.-standardised thermometer.

The main thermostat bath for use below room temperature was similar to that of Benford and Ingold (*J.*, 1938, 929) and Benford (*J. Sci. Instr.*, 1936, **13**, 14). The evaporator cylinder of an Electrolux refrigerator, unit type 42A2, having an absorption rate of 5×10^4 cal. hr.$^{-1}$ at 0°, at an input of 400 w, was inserted into a copper sleeve projecting into the thermostat bath. The sides and bottom of the tank were insulated with a 2" layer of glass-wool. The refrigerator was adjusted to keep the bath 2—3° below the desired working temperature.

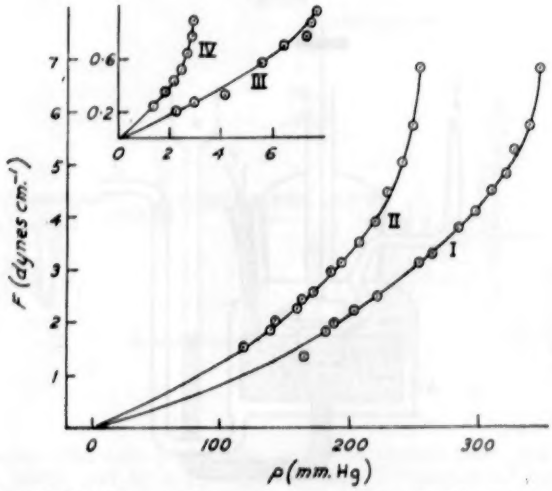
Determination of Adsorption Isotherms.—After temperature equilibrium had been established, and a clean surface prepared by flushing with water at the same temperature, the stopper, with the wet plate suspended through *H* by a fine aluminium suspension, was inserted. After adjustment of the stopper for coincidence between *O* and *P* (see Fig. 2), the suspension was attached to the balance, thus pulling the plate up through the surface, and the balance released and equilibrated. With the same plate the weight on the balance necessary for equilibrium was predetermined. The plate was then allowed to drain, and the scale reading P_1, corresponding to the surface tension of the clean surface γ_0, read. Meanwhile the temperature of the Dewar

thermostat was adjusted to *ca.* −30°, and the needle valve on the nitrogen cylinder was carefully and slowly adjusted to give a slow stream of bubbles until the flow-meter registered the correct value.

As the nitrogen carried the adsorbate vapour over the surface, the scale reading gradually decreased, owing to the fall in γ on adsorption, and eventually became constant at a reading P_2 corresponding to the surface tension of the film-covered surface. Owing to the displacement of the air originally present, a lag of some minutes elapsed before this reading became constant. From the values of $\Delta P (= P_1 - P_2)$, F was calculated from equation (2) or (4).

The temperature of the Dewar thermostat was increased until the saturation vapour pressure was reached and a complete adsorption isotherm was thus obtained. At lower surface pressures increments of 2° or 3° were usual, but near saturation the temperature was raised slowly in steps of 0·1° or 0·2°, since in this region large changes in surface pressure occur with small changes of partial pressure. For this reason accurate values in the neighbourhood of saturation were more difficult to obtain, and very close thermostatic control of both thermostats was essential. With *n*-pentane at 0° it was found impossible to obtain a reproducible value at

FIG. 3.



I, *n*-Pentane (15·0°); II, *n*-pentane (7·5°); III, *n*-octane (15·0°); IV, *n*-octane (0°).

saturation, and an "instability" of the type noted by Cassel and Formstecher (*Kolloid Z.*, 1932, **61**, 18) seemed to occur. This trouble was not encountered, however, at the other temperatures, or with the other adsorbates.

All the isotherms were repeated in quadruplicate with good agreement. Blank experiments with water in the bubbler and in the trough had demonstrated that the passage of nitrogen alone had no appreciable effect on the film balance.

Results and Discussion

The experimental results are given in Table 2. Fig. 3 illustrates the form of the F–p curves obtained in all these cases.

The adsorption excess $\Gamma_2^{(1)}$, referred to later in this paper as Γ, is given by the Gibbs equation

$$\Gamma_2^{(1)} = \frac{-\mathrm{d}\gamma}{RT \,.\, \mathrm{d} \ln a_2} = \frac{\mathrm{d}F}{2{\cdot}303RT \,.\, \mathrm{d} \log_{10} p_2} \quad . \quad . \quad . \quad . \quad . \quad (5)$$

It can be assumed that the vapours will obey the perfect-gas laws adequately, and also that Dalton's law can be applied with sufficient accuracy to the vapour phase. From a

TABLE 2.

F is expressed in dynes cm.$^{-1}$, p in mm. Hg.

n-Pentane

7·5°		15°		0·0°		*n*-Hexane 7·5°		15°	
F	p	F	p	F	p	F	p	F	p
1·50	118·3	1·82	181·6	0·60	16·46	0·72	26·67	0·79	38·42
1·85	139·0	1·92	187·1	0·89	22·88	0·83	30·62	1·00	47·86
1·99	143·2	2·19	204·2	0·93	24·66	0·94	34·47	1·13	51·17
2·27	159·6	2·45	220·8	1·08	26·67	1·13	38·15	1·19	54·20
2·43	162·6	3·09	253·5	1·18	29·24	1·32	44·87	1·28	57·02
2·52	171·0	3·26	264·2	1·36	31·62	1·56	50·35	1·41	61·09
2·96	186·2	3·76	284·4	1·40	33·04	2·15	59·16	1·54	65·16
3·08	193·2	4·08	296·5	1·75	36·82	2·53	62·23	1·61	66·76
3·52	207·0	4·47	309·7	2·05	40·65	3·26	65·61	1·73	71·12
3·89	219·3	4·80	321·4	2·46	43·25	3·65	66·53	1·83	74·13
4·44	229·6	5·24	328·1	2·80	44·36			2·04	77·45
5·01	241·0	5·71	338·8	3·42	46·00			2·44	84·14
5·69	248·9	6·81	346·7					2·66	88·72
6·83	254·1							2·83	91·62
								3·53	95·94

n-Heptane

0·0°		7·5°		15°				*n*-Octane 0·0°		15°	
F	p	F	p	F	p	F	p	F	p	F	p
0·32	4·87	0·34	7·16	0·36	9·25	1·07	22·60	0·24	1·35	0·20	2·24
0·40	5·57	0·43	7·85	0·43	11·18	1·11	23·23	0·35	1·79	0·27	2·94
0·48	6·35	0·53	9·28	0·51	13·34	1·17	23·26	0·43	2·15	0·34	4·18
0·58	7·35	0·70	11·45	0·58	15·40	1·29	25·12	0·52	2·45	0·57	5·59
0·67	8·30	0·78	12·71	0·66	16·10	1·46	26·00	0·65	2·69	0·71	6·41
0·77	9·27	0·95	14·66	0·70	17·38	1·68	26·50	0·76	2·86	0·77	7·23
0·85	9·62	1·02	15·35	0·73	17·95	1·75	27·16	0·89	2·94	0·88	7·48
1·05	10·60	1·09	15·74	0·79	18·67					0·97	7·69
1·07	10·86	1·24	17·04	0·89	20·23						
1·34	11·18	1·56	17·58	0·94	21·58						
1·67	11·45	1·63	17·68	1·04	22·05						

2 : 2 : 4-Trimethylpentane

0·0°				7·5°				15°			
F	p	F	p	F	p	F	p	F	p	F	p
0·58	5·88	1·56	9·48	0·58	7·43	1·91	15·76	0·79	13·40	2·11	23·23
0·63	6·21	1·92	10·69	0·74	9·08	2·73	18·20	0·96	15·17	2·41	25·35
0·84	7·18	2·74	12·09	0·85	10·67	2·83	18·24	1·04	16·11	2·82	26·24
1·07	8·32	3·41	12·70	0·95	10·86	3·41	19·21	1·10	17·54	3·08	27·99
1·12	8·39	4·07	13·06	1·25	12·91	3·88	19·82	1·43	20·37	3·32	28·18
				1·66	15·38			1·87	22·86	3·90	29·58

graph of F against $\log_{10} p_2$, the values of $dF/d \log_{10} p_2$ were determined mechanically, at various F values, and Γ calculated from the equation (5). The isotherms are shown in Figs. 4 and 5. For the hydrocarbons it was found that, at constant vapour pressure, the adsorption decreases with increasing temperature; at the same vapour pressure and the same temperature, the adsorption increases markedly with the length of the hydrocarbon chain; at the same temperature, the order of adsorption at similar values of p/p_0, including saturation, is $C_5 > C_6 > C_7 > C_8$, and 2 : 2 : 4-trimethylpentane is intermediate between *n*-hexane and *n*-heptane.

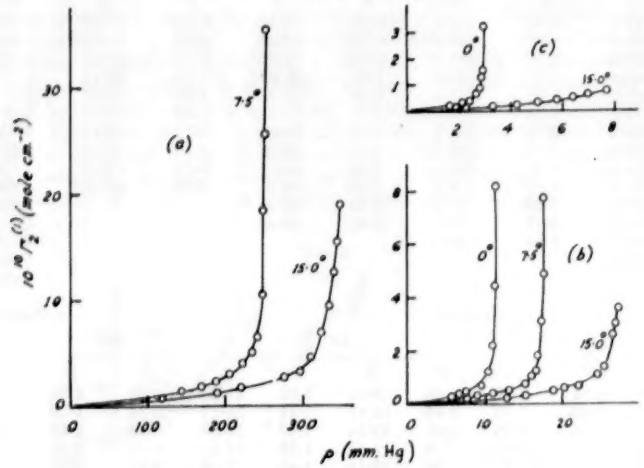
In all the cases investigated the adsorption isotherms can be expressed fairly accurately by the empirical equation

$$\Gamma = Bp/(1 - k_1 p) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where B and k_1 are constants. This is an equation to a rectangular hyperbola, whose asymptotes are $\Gamma = -B/k_1$ and $p = 1/k_1$; the curve to the equation passes through the origin and is convex to the p axis. Fig. 6 shows the good linear relationship of Γ/p and Γ for *n*-pentane and *n*-octane, and in Fig. 7*b* are the experimental and calculated curves for 2 : 2 : 4-trimethylpentane. In all cases $1/k_1$ is greater than p_0, and therefore at saturation,

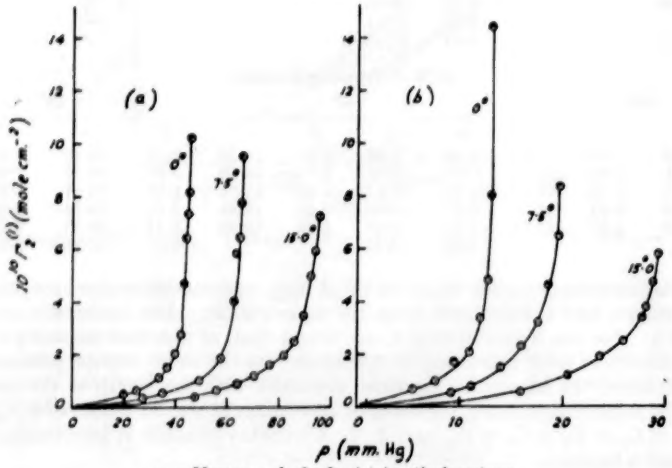
or very near it, a finite value for the adsorption is obtained. An isotherm of this form is obtained in the B.E.T. model only for unrestricted adsorption, and in the special case when $c = 1$ (or $\sigma_1 = \sigma_2 = \sigma_3$, etc.); the absence of the point of inflection for this case, realisable or not, follows from the equality of σ_1, σ_2, etc. (see Jones, *J.*, 1951, 126). It should be

FIG. 4.



a, *n*-Pentane; *b*, *n*-heptane; *c*, *n*-octane.

FIG. 5.



a, *n*-Hexane; *b*, 2 : 2 : 4-trimethylpentane.

noted, however, that this model requires the asymptote equation to be $p = p_0$ (since $\sigma_2\mu$ is put equal to p/p_0). The experimental data, as is to be expected, do not fit this model. The type of deviation is instructive, however; values of c ($= \sigma_1/\sigma_2$) can be chosen so that the experimental data fit the theory approximately at the lower pressures, and a rough agreement can be extended in some cases even up to $0{\cdot}6p/p_0$, but the theoretical curve deviates increasingly from the experimental as the pressure increases further, so that when p/p_0 is 0·8 the theoretical adsorption is much greater than the experimental. This is because these

curves are asymptotic at a value of p greater than p_0, so that the rapid adsorption increase occurs at a higher value of p than in the B.E.T. theory, and may be found, theoretically, above the saturation point. This could be interpreted, apart from the general unsuitability of the B.E.T. model, as due to either changes in the values of c as adsorption increases or

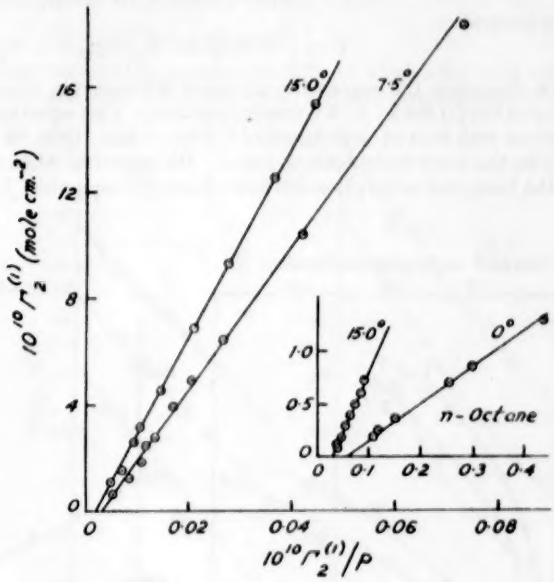


FIG. 6.
n-Pentane.
Inset: *n*-octane.

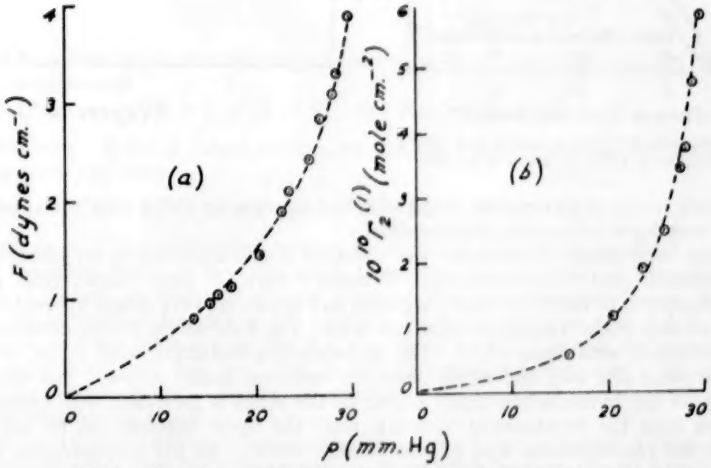


FIG. 7.

Broken lines represent calculated curves and circles experimental values.

the fact that $\sigma_{2^1\mu}$ is greater than p/p_0, which is the assumption made in the Anderson model (*J. Amer. Chem. Soc.*, **1946**, **68**, 686). It has been found, however, that neither Anderson's equation nor that of Hüttig (*Monatsh.*, **1948**, **78**, 177) gave agreement with the experimental results. Good agreement, up to 90% of saturation in some cases, was found with Barrer and Ferguson's equation (*Trans. Faraday Soc.*, 1950, **46**, 403, equation 22), which was obtained

by embodying Anderson's assumption into the Hüttig equation. This agreement would warrant further consideration of this model.

Equation (2) when combined with that of Gibbs gives

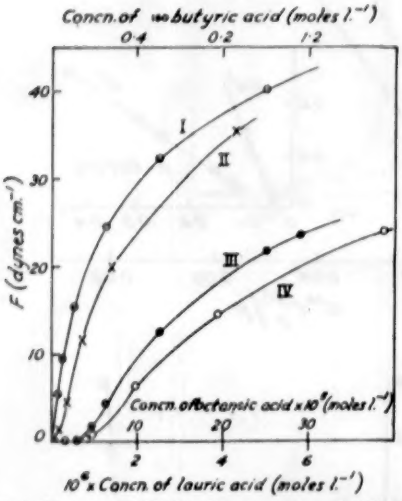
$$dF = BRT\, dp/(1 - k_1 p)$$

and on integration

$$F = -(2{\cdot}303BRT/k_1) \log_{10} (1 - k_1 p) \quad . \quad . \quad . \quad . \quad . \quad (7)$$

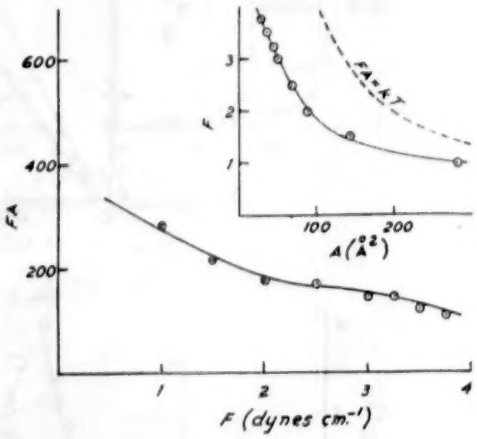
Fig. 7*a* illustrates the agreement obtained between the observed and calculated results from equation (7) for 2 : 2 : 4-trimethylpentane. This equation, save for two sign changes, is identical with that of Szyszkowski (*Z. Phys. Chem.*, 1908, **64**, 385), which agrees with his results for the lower fatty acids on water. His equation, when combined with that of Gibbs, gives the Langmuir adsorption isotherm (Case I) (Langmuir, *J. Amer. Chem. Soc.*, 1918, **40**,

FIG. 8.



I, *iso*Butyric acid (18°); II, octanoic acid (25°); III, lauric acid (18°); IV lauric acid (29°).

FIG. 9.
2 : 2 : 4-Trimethylpentane.



1361) which is also a rectangular hyperbola, but concave to the p axis; it approaches a limiting monolayer adsorption asymptotically.

In these experiments no evidence was obtained of any approach to an adsorption limit in the realisable part of the isotherm. Frumkin's work (*Z. phys. Chem.*, 1925, **116**, 482) on the adsorption of the fatty acids, octanoic and lauric, on very dilute hydrochloric acid, provides an important comparison with this work; Fig. 8 shows the F–concentration curves that he obtained with these acids. The corresponding *iso*butyric acid curve, determined by Szyszkowski (*loc. cit.*), and which obeys his equation, is also shown. The effect of the attraction of the hydrocarbon chain is seen as the series is ascended, with corresponding deviations from the Szyszkowski equation, until the curve becomes (as for the C_8 acid) *convex* to the concentration axis (cf. the present work). As the concentration increases, however, they show a point of inflection and at higher concentrations again obey the Szyszkowski equation, thus indicating an approach to a limiting value of adsorption. In this work no evidence of this was found; in fact, $d\Gamma/dp$ continually increases up to (or very near to) the saturation pressure.

The surface area per molecule, A, was calculated from $A = 1/\Gamma N$, and the F–A and FA–F relations were studied. Fig. 9 shows the results obtained for 2 : 2 : 4-trimethylpentane at 15°. In the F–A curves, very similar to the P–V curves for gases, the values

of A for a given value of F are always less than those corresponding to the perfect-gas equation; this is shown also in the FA–F relation, which is reminiscent of real-gas curves at low pressures, where the attractive correction is predominant, and where, over small pressure ranges, the FA–F curves are approximately linear. It can be shown from a surface equation of condition, analogous to that of van der Waals

$$(F + a/A^2)(A - b) = kT \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

that, if A is very large, b can be neglected in comparison with A; so also the term a/A^2 can be neglected, giving the perfect-gas law. If A is smaller, but still large enough, b can be

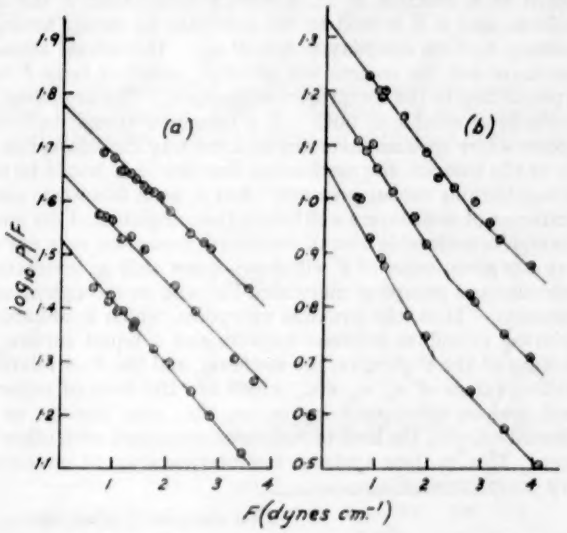


FIG. 10.
a, *n*-Hexane.
b, 2 : 2 : 4-Trimethylpentane.

neglected to a first approximation in comparison with A, but this may not be so with a/A^2. The equation

$$(F + a/A^2)A = kT \quad \text{or} \quad FA = kT - a/A$$

is thus obtained. If the A values are not too small a/A can be put equal to aF/kT in the correcting term, and then

$$FA = kT - aF/kT \quad \text{or} \quad FA = kT - b'F \ (b' = a/kT)$$

At low values of F this expression holds approximately. It should be emphasised that, owing to the small values of F in our work, there were certain errors in the values for A. At small A values, A becomes almost constant and approximately equal to b, and equation (8) becomes $FA = kT + bF$. This is Volmer's equation and FA/F is linear, with slope b, and the intercept on the FA axis equal to kT. This is the equation that Kemball and Rideal (*Proc. Roy. Soc.*, 1946, *A*, **187**, 53) found to fit their results for adsorption on a mercury surface so well. In our experiments a similar linear relation holds approximately, but the slope is negative.

As was shown by Cassel and Formstecher (*loc. cit.*), if the values of A from Volmer's equation are substituted in the Gibbs equation, the relation between F and p is

$$\ln p/F = (bF/kT) + C \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

This linear relation between $\ln p/F$ and F holds reasonably well at low values of F, but with a negative gradient. As F increases, the linear relation holds for the *n*-hydrocarbons, but in some other cases, a change in curvature, or even a definite break in the line, occurs (see Fig. 10). (Other instances of this behaviour will be found in Part III.)

It is noteworthy that in an equation of the Volmer form the constant b' (apart from its physical significance) could be put equal to the difference of two constants ($b - K'$), and an equation of state produced that is of the form $[F + K'F^2/(1 - K'F)](A - b) = \boldsymbol{k}T$, where K' is a cohesion constant. Substituting for A in the Gibbs expression, and integrating, we again have an expression of the same form as equation (9), $\ln p/F = DF + C$; the slope of the $\ln p/F$–F line is D ($= b/\boldsymbol{k}T - K'$) and the slope and its value depend on the relative values of b and K'; in our experiments K' is greater than $b/\boldsymbol{k}T$.

This idea of a gas film, whose molecular area can be studied as a function of F, considered as the analogue of a gas in an enclosure from which it cannot escape, whose volume can be studied as a function of P, is readily understood if the adsorbate is non-volatile and insoluble, and if it is held to the substrate by strong forces (large σ_1), and there is little tendency to form multilayers (small σ_2). The lateral attraction of the molecules in the monolayer and the co-area will affect A, which at large F values will approach that area corresponding to the compressed monolayer. This argument is not affected if the substrate is volatile or soluble or both. If a Langmuir trough technique could be applied to these vapour–water systems, avoiding in some way the adsorption of vapour on the clean-water side of the balance, the mechanical decrease in A would be accompanied by an increase in the equilibrium vapour pressure. But if, as in this work, conditions are favourable for the occurrence of multilayers well before the completion of the monolayer (small σ_1 and large σ_2), although considerable overall multilayer formation may not occur in any case, the value of A at any given value of F will depend, not only on interactions in the monolayer between molecules and groups of molecules, but also on the extent and character of the multilayer formation. Thus, the dynamic viewpoint, which is so naturally applied to these systems involving equilibria between vapours and a liquid surface, leads to the conclusion that the form of the F–p curve, the isotherm, and the F–A relationships are determined by the relative values of σ_1, σ_2, etc., which are the lives of molecules on the adsorbed surface itself, and on subsequent layers; σ_2, etc., may also be, as in Langmuir's Case IV (with different values), the lives of molecules associated with other adsorbed molecules in a monolayer. Thus in these systems, the interpretation of surface equations of condition may be very complicated.

Free energies of adsorption

$-\Delta G$ has been calculated from Kemball and Rideal's equation (*loc. cit.*)

$$-\Delta G = \boldsymbol{R}T \ln 12{,}500\partial F/\partial p(F \to 0) \quad . \quad . \quad . \quad . \quad . \quad (10)$$

Rewriting $\ln p/F = DF + C$ as $p = Fe^{(DF+C)}$, and differentiating, we have $\partial F/\partial p(F \to 0) = e^{-C}$, which in combination with (10) gives

$$-\Delta G = 2{\cdot}303\boldsymbol{R}T(4{\cdot}0969 - C)$$

so that the free energies of adsorption can be calculated from the intercept C on the graph of $\log_{10} p/F$ against F. The values so obtained are listed in Table 3.

TABLE 3.

	0·0°	7·5°	15·0°		0·0°	7·5°	15·0°
n-Pentane	—	2714	2649	*n*-Octane	4083	(3994)	3905
n-Hexane	3205	3134	3052	2 : 2 : 4-Trimethyl-			
n-Heptane	3585	3499	3420	pentane	3792	3730	3661

In Fig. 11, $-\Delta G$ is plotted against the number of carbon atoms in the *n*-saturated hydrocarbons. There is a linear relation, the increase per carbon atom being *ca.* 420 cal. mole^{-1}, a quantitative statement of Traube's rule as applied to these *n*-saturated hydrocarbons themselves.

Mono- or Multi-layers.—If the overall film thickness is defined as $d = 100\Gamma/\Gamma_m$, where Γ_m is the surface excess for a monolayer calculated for a flat molecular orientation with a maximum hydrocarbon–water interface, multimolecular layers are formed in many cases. Fig. 12 shows how the percentage of monolayer varies with p/p_0 for the *n*-hydrocarbons at 15°. If d is calculated on the basis of vertically orientated molecules, approximately a

monolayer, or less, is obtained in most cases at saturation. Only in the cases of *n*-pentane and 2 : 2 : 4-trimethylpentane at 0° is a second layer completed, although in some other cases it is approached. The numerical data for *d*, for these two limiting orientations, are given in Table 4.

TABLE 4.

	0·0°			7·5°			15°		
	Γ	*d*	*d*	Γ	*d*	*d*	Γ	*d*	*d*
	$p = p_0$	flat	vert.	$p = p_0$	flat	vert.	$p = p_0$	flat	vert.
n-Pentane	—	—	—	35·5	1016	430	18·9	547	228
n-Hexane	10·3	314	124	9·5	295	115	7·3	228	87
n-Heptane	8·2	282	99	7·7	270	94	3·6	126	43
n-Octane	3·2	124	39	—	—	—	0·7	28	—
2 : 2 : 4-Trimethylpentane	14·5	511	276	8·4	298	159	5·8	208	109

For *n*-hydrocarbons in the vertically orientated position, a cross-sectional area of 20 sq. Å has been assumed (see Muller, *Proc. Roy. Soc.*, 1932, *A*, **138**, 514). It seems probable that flat orientations would be preferred when Γ is small but that with films of this kind,

FIG. 11.

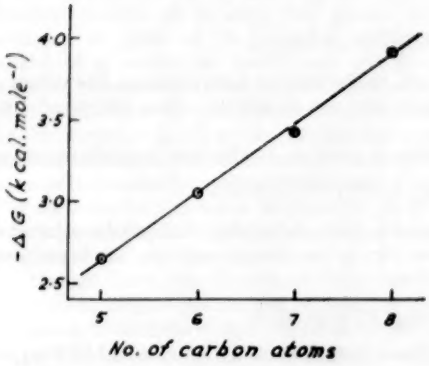
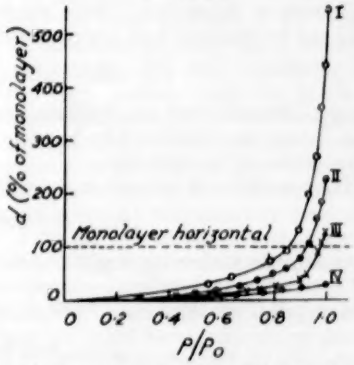


FIG. 12.



I, *n*-Pentane; II, *n*-hexane; III, *n*-heptane; IV, *n*-octane. The broken line corresponds to one horizontal monolayer.

weakly attached to the substrate, a variety of groupings of adsorbed molecules, with varying orientations, would be found as Γ increased. The larger hydrocarbon–hydrocarbon affinity would be satisfied, under more crowded conditions, either by multilayers which are disposed in a more or less flat orientation or by groups of molecules in a more upright one.

If this conclusion is correct, overall multilayer formation would seem to be occurring in all cases with the exception of *n*-octane, and the rapidly increasing Γ values, when p/p_0 exceeds about 0·85, are due then to the large σ_2 values produced by hydrocarbon–hydrocarbon attraction.

The change of gradient in some of the $\log_{10}(p/F)$–F curves must be associated with these changes, but a consideration of this will be reserved for a later paper. It will be noticed, however, that the change of slope (Fig. 10) corresponds to a decrease in the value of the intercept C, and an *increase* in the value of $-\Delta G$ as the adsorption proceeds. This would be in agreement with the above views and with those expressed in Part I.

Comparison of $-\Delta H$ with the Heats of Liquefaction.—From the temperature coefficients of $-\Delta G$ shown in Table 3, and by using the Gibbs–Helmholtz equation, $\Delta G - \Delta H = T(\mathrm{d}\Delta G/\mathrm{d}T)$ values for $-\Delta H$ have been calculated which, in Table 5, are compared with the heats of liquefaction of the adsorbates: the latter are taken from the data of the National Bureau of Standards (Circular C **461**, "Selected Values of Properties of Hydrocarbons"). All values are in cal. mole^{-1}; the heats of adsorption are at 7·5°. These heats of adsorption

increase fairly steadily as the series is ascended, the average increase in $-\Delta H$ per carbon atom being *ca.* 720 cal. mole^{-1}; $-\Delta H$ of adsorption is in all cases less than the liquefaction heat. As is seen from the last column, these differences are considerable, and increase with the number of carbon atoms. Taking as a plausible assumption that these differences correspond approximately to the $(E_1 - E_L)$ of the B.E.T. theory, we can calculate from $c = \sigma_1/\sigma_2 = ca.\ e^{(E_1 - E_L/RT)}$, that for *n*-pentane, $c = ca.\ 0{\cdot}11$, and for *n*-octane, 0·001. As has been discussed in Part I, σ_1 for *n*-octane is much greater than for *n*-pentane, and the results now obtained give a degree of quantitative support to the qualitative view previously expressed, that the increase in σ_2 much outweighs the increase in σ_1 as the *n*-saturated hydrocarbon series is ascended.

TABLE 5.

	$-\Delta H$ of adsorption	$-\Delta H$ of liquefaction	$\Delta H_L - \Delta H_{Ads.}$
n-Pentane	5146	6460	1314
n-Hexane	5995	7690	1695
n-Heptane	6585	8900	2315
n-Octane	7324	10,070	2746
2 : 2 : 4-Trimethylpentane	6179	8530	2251

Entropy of Adsorption.—From the values of $-\Delta G$ and $-\Delta H$ already obtained, values of ΔS can be obtained from the equation

$$\Delta G - \Delta H = T(\mathrm{d}\Delta G/\mathrm{d}T) = -T\Delta S$$

Owing to the relatively small differences in $-\Delta G$ at the various temperatures, the values of $-\Delta S$ cannot be considered to be accurate data, but are of interest when compared with values obtained theoretically.

The translational entropy in three dimensions is given by the Sackur–Tetrode equation

$$_3S_{trans.} = 2{\cdot}303\boldsymbol{R} \log_{10} (M^{3/2}T^{5/2}) - 2{\cdot}30$$

where M is the molecular weight and the entropy is given in cal. deg.$^{-1}$ mole^{-1} for a pressure of 1 atm. The translational entropy expression for a two-dimensional gas has been given by Kemball (*Proc. Roy. Soc.*, 1946, *A*, **187**, 73) as

$$_2S_{trans.} = 2{\cdot}303\boldsymbol{R} \log_{10} \boldsymbol{MTa} + 65{\cdot}80$$

where a is the area per molecule, defined in the standard state as equal to $22{\cdot}53T$ sq. Å. The values calculated from these equations are given in Table 6. From a comparison of the last two columns the entropy changes could be accounted for as being approximately

TABLE 6.

	$_3S_{trans.}$	$_2S_{trans.}$	$_2S_{trans.} - {}_3S_{trans.}$	ΔS (expt.)
n-Pentane	38·6	29·8	8·8	8·7
n-Hexane	39·1	30·1	9·0	10·2
n-Heptane	39·6	30·4	9·1	11·0
n-Octane	40·0	30·7	9·3	9·5
2 : 2 : 4-Trimethylpentane	40·0	30·7	9·3	8·7

equivalent to the loss in the adsorbed state of one degree of translational freedom only. This would be in accordance with the previous conclusions that the adsorbate molecules are being weakly held by relatively small forces in the field of force of the surface.

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The Delocalisation of Electrons in Solid Organic Complexes of Anthracene.

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To elucidate the nature of the bonding, comparative studies have been made on the lithium, sodium, and potassium complexes with anthracene. Methods are described for varying the alkali content x of the solid complexes, $M_x(C_{14}H_{10})$, over a range $x = 1{\cdot}1$ to $2{\cdot}12$ in the case of sodium.

A marked contraction in volume is observed on forming complexes up to the formula $M_2(C_{14}H_{10})$; this contraction depends on the electropositivity of the alkali metal. Measurements on the electron polarisability, electronic conductivity, and other properties of the solids give results suggesting the formation of quasi-metallic bonds between the alkali metal and the aromatic hydrocarbon.

This investigation continues previous studies on the delocalisation of electrons in crystals, associated with special types of crystal bonding. At first sight, the range of crystalline solids with metallic properties appears to be limited by the range of atoms in the Periodic System capable of forming the special type of co-operative bonding characteristic of metals. In spite of its powerful mathematical advantages, the Bloch–Brillouin zone model of a crystalline metal does not indicate any very obvious guide for predicting metallic behaviour in a crystal. On the other hand, though it is less suited for the quantitative study of co-operative properties the Pauling model permits a more chemical approach. In this model, a metal crystal is regarded as a giant molecule made up of atoms bonded by covalent linkages, but with a defect of electrons. Transport of electricity without transport of mass is chemically equivalent to electron switching from one site to another in the crystal. For semi-conducting solids Wagner (*Z. phys. Chem.*, 1933, **22**, *B*, 212) has described a model which has analogies with the local or chemical features of Pauling's description of metallic bonding.

Though there may be serious deficiencies in " chemical " models for discussing quantitative co-operative parameters of metallic solids, they do point to an important possible extension of the field of metallic behaviour. Certain types of organic molecules appear to be capable of functioning like the units of structure in crystalline metals. The largest group of such structures is formed by aromatic compounds. Particularly when these contain several fused aromatic nuclei, their electronic characteristics should begin to approximate to those of graphite (cf. Ubbelohde, *Nature*, 1933, **132**, 1002).

Experimental evidence developing these views is beginning to accumulate. The metallic behaviour of solid complexes of graphite with potassium and with bromine has been described by McDonnell, Pink, and Ubbelohde (*J.*, 1951, 191). Both types of complex show a marked increase in general metallic properties, compared with the parent graphite. This behaviour can be interpreted by assuming that layers of fused aromatic nuclei in the crystals act as both electron acceptors and electron donors, and form covalent bonds, as in the Pauling chemical model of a metal. With smaller fused aromatic molecules, the ease of electron switching may be lessened, and the properties of the solid complexes lie nearer to those of a metalloid or semi-conductor solid. For example, with anthracene the alkali metals lithium, sodium, and potassium form solid complexes (Holmes-Walker and Ubbelohde, *J.*, 1954, 720) whose magnetic properties are consistent with quasi-metallic bonding between the alkali atoms and the aromatic molecules, and whose electrical properties are those of semi-conductors. Again, a complex between perylene and bromine (Akamatu, Inokuchi, and Matsunaga, *Nature*, 1954, **174**, 168) exhibits electrical conductivity much greater than that of the parent aromatic hydrocarbon.

The present paper deals with the development of more precise methods than those hitherto available for studing some characteristic properties of these complexes in the solid state. Ways are described for obtaining solids M_xAn in which the proportion x of alkali metal (M) to anthracene (An) can be varied between about 1·1 and 2·12.

The specific volumes of such solids have been determined as a function of x and M, for lithium, sodium, and potassium complexes. By using alternating-current and improved direct-current measurements, electron polarisabilities, electrical conductances, and dielectric-loss factors have also been evaluated for these complexes.

As discussed below, the more extensive information now obtained supports the interpretation previously given, *viz.*, that the bonding between the alkali-metal atoms and the aromatic groups is quasi-metallic. The dark, sodium-rich complexes with $x > 2$ show particularly marked enhancement of the pseudo-metallic properties.

Experimental

Nitrogen was purified in a manner similar to that described by Holmes-Walker and Ubbelohde (*loc. cit.*). The gas (British Oxygen Co.) was freed from oxygen by passage at a low linear velocity through commercial copper turnings electrically kept at 500°. A mild-steel tube, 2″ in diameter and 3′ long, with screwed end-caps, was used to contain 1¼ kg. of copper turnings. The issuing gas was dried by a 6 ft. column of potassium hydroxide pellets, followed by a 2 ft. column of magnesium perchlorate, and finally a liquid-air trap packed with chemically clean glass-wool (cf. Ubbelohde, *J.*, 1933, 972). After each cylinder of commercial nitrogen had been used, the copper was regenerated by reduction with a current of hydrogen at 500°.

Very great care is necessary in preparing the solid complexes in solvent-free form, and sufficiently pure to permit reliable measurements of important physical properties. Improvements in previously published details for handling these compounds (Holmes-Walker and Ubbelohde, *loc. cit.*; Reid and Ubbelohde, *J.*, 1948, 1597) were as follows:

All solvents were rigorously dried and handled throughout under pure nitrogen. Diethyl ether was purified as described by Mackle and Ubbelohde (*J.*, 1948, 1161). 1 : 2-Dimethoxyethane was not commercially available when most of this work was carried out. It was prepared by methylating 2-methoxyethanol with methyl sulphate by a method provided by Professor Wright (Toronto University, personal communication). It was purified by storage over sodium under nitrogen. Removal of final traces of water was achieved by adding just sufficient dried benzophenone to produce the blue ketyl, and then distilling off the solvent under nitrogen. Benzene ("AnalaR") was first dried by refluxing over sodium wire under nitrogen. The benzene was then distilled off and stored over sodium wire. Before use it was distilled directly into the required container. Anthracene (British Drug Houses) was purified by molecular distillation (f. p. 214°). Rather better results were found with material obtained from the Deutsche Gesellschaft für Teerverwertung (f. p. 215·0° after sublimation). Purification and handling of the alkali metals was as previously described (McDonnell, Pink, and Ubbelohde; Holmes-Walker and Ubbelohde, *locc. cit.*).

Preparation of Complexes.—Earlier workers (Schlenck, *Ber.*, 1914, **47**, 473; Scott *et al.*, *J. Amer. Chem. Soc.*, 1936, **58**, 2442) were not concerned with the isolation of the solid complexes. Accordingly, the particulars below detail especially the steps in isolating these solids. The addition complexes were generally formed by direct interaction of alkali metal and hydrocarbon in dimethoxyethane–diethyl ether (1 : 10) (cf. Scott *et al.*, *loc. cit.*). Successful preparations were also carried out in cyclic ethers and in pyridine, though these were not used for the physical measurements. Access of direct sunlight was prevented by using black cloth wrappings on the containing vessel (Reid and Ubbelohde, *J.*, 1948, 1897).

In a typical preparation pure anthracene (10 g.) was placed in a 1-l. three-necked flask with constant turning over of the powder and gentle warming under a flow of nitrogen for about 6 hr. to ensure complete expulsion of all moisture and oxygen. Approx. 600 c.c. of solvent were then added either by distilling or syphoning in, again under nitrogen.

On introduction of excess of alkali metal either as cubes or as sodium sand, protected by nitrogen, the reaction generally started immediately. Occasionally an induction period was noted. This could be eliminated by the addition of a small drop of slightly damp solvent. Presumably, this catalysed the reaction by breaking up a surface film of oxide on the alkali metal or by providing a medium for ionic reactions. Potassium was introduced by breaking sealed ampoules of metal under the solvent in the reaction flask.

Within approx. 10 min. of the onset of the reaction the whole solution was deeply coloured, purple in the case of lithium and indigo for both sodium and potassium. Stirring was continued as long as possible (7 days), normally terminated by the evaporation of all free solvent. The highly coloured solid was then broken up and warmed to remove all co-ordinated solvent. Recovery tests on solids prepared in dimethoxyethane–diethyl ether showed that the solvent

at first retained in the complex was dimethoxyethane, and special preparations in unmixed solvents were used in the attempt to determine its proportion. Direct weighing of the reaction flask before and after warming showed that, before warming, up to 1 mole of dimethoxyethane was retained for every 2 g.-atoms of alkali metal. Values obtained with diethyl ether were similar, but not very reproducible owing to the greater volatilisation of this ether even before warming. The resulting solvent-free homogeneous powder was yellow for lithium, red-brown for sodium, and grey for potassium. Any pieces of metal which had escaped reaction could then be picked out with tweezers, as they remained bright.

The empirical formula of the complex solid M_xAn could next be varied in the range $x = 0$ to $x = 2$ by elutriating out excess of anthracene with hot benzene (cf. Holmes-Walker and Ubbelohde, *loc. cit.*).

Complexes with $x > 2$ were only investigated in the case of sodium and were prepared by two methods. On heating the M_2An complex (prepared as above) in a high vacuum to above 200°, small amounts of anthracene crystals appeared on the surface of the powder. This "sublimed" anthracene was removed by washing out with hot benzene, and the process repeated. Approximately ten such sublimations were required to reach the $M_{2\cdot12}An$ formula. The second method of preparation of metal-rich complexes consisted in heating the M_3An complex in a high vacuum to 120° in an atmosphere of alkali-metal vapour. Complexes were obtained up to the $M_{2\cdot12}An$ formula by both methods.

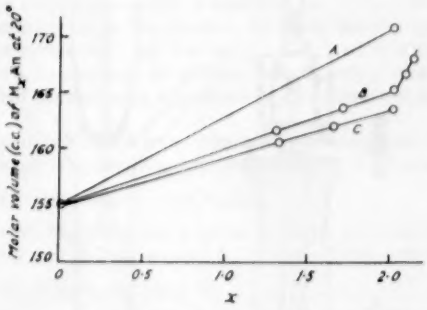


FIG. 1.
A, K–anthracene.
B, Na–anthracene.
C, Li–anthracene.

Analysis.—About 1 g. of the complex was transferred into a 3-necked weighing bottle previously swept out by nitrogen. This known quantity was then decomposed by a 1 : 1 mixture of dilute sulphuric acid and absolute alcohol and evaporated to dryness under infrared lamps. From the solid residue all the hydrocarbon could be extracted quantitatively by repeated washings with benzene. The inorganic residue was then removed and weighed as sulphate, the precautions described by Vogel ("Quantitative Inorganic Analysis," Longmans, London, 1947) being used. The hydrocarbon recovered from complexes with formula M_2An was identified (mixed m. p.) as 9 : 10-dihydroanthracene. For complexes with $x > 2$ only dihydroanthracene was recovered, whereas with $x < 2$ a mixture of anthracene and dihydroanthracene was found.

Density Measurements.—A conventional pyknometer was fitted with two ground-glass joints (A.7) to facilitate weighing under nitrogen. Purified Nujol was used as the pyknometer fluid. This was first thoroughly dried by bubbling nitrogen through it at 120° for 48 hr. Density measurements were found to be reproducible to within ±0·001 g./c.c. Molar volumes obtained from density measurements by multiplying the specific volume by the mass of complex containing one mole of anthracene are recorded in Fig. 1.

Molar Polarisations.—Direct measurements of the optical refractivities were prohibited by the highly reactive nature and low solubility of the solid complexes. Molar polarisations were evaluated from measurements of the dielectric constants of the powdered solids.

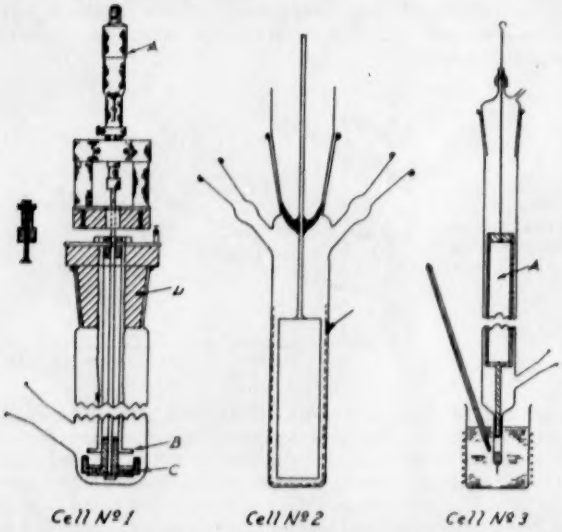
Polarisation of powdered solids and the evaluation of the true dielectric constant have been extensively discussed by Böttcher ("Theory of Electric Polarisation," Elsevier, 1952). Three types of cell (Fig. 2) were used for the dielectric and conductivity experiments. All three were designed to permit filling and use under nitrogen. To achieve filling, a transference tube was used fitted with two joints, one connected to the cell, and the other to the flask containing the powdered complex. Rotation at the greased ground-glass joints enabled filling to be accomplished with full nitrogen protection.

Cell No. 1. This cell was designed to permit measurements of dielectric constant and

dielectric loss to be made on the samples of the powdered complexes under moderate compression. A micrometer screw *A* served both to measure the thickness of the sample and to apply known values of compression by means of the friction drive. From the accompanying diagram it will be seen that the circular cell electrodes *B* + *C* (outside diam. 35 mm.) are mounted so that the cell spacing is directly measurable on the micrometer. All the metal parts were made from brass. Insulation between the two electrodes was by polystyrene throughout (heavily shaded) chosen for rigidity and low loss factor. The tapered joint (B.50) was machined from Tufnol as were the two mounting platforms for the micrometer head. The complete electrode assembly and micrometer head were movable in the vertical plane by means of the threaded brass tube *D*. A small hole (not shown) drilled in *D* enabled the nitrogen flow to escape up the inside of the threaded tube *D*.

A cylindrical, earthed, copper screen surrounded the cell when in use. For measurements of dielectric loss, the cell was found to be satisfactory, but owing to the relatively large amount of dead capacity a different design of cell was preferred for evaluations of the dielectric constant.

FIG. 2.



Cell No. 2. A concentric cylindrical electrode arrangement was used in this design. This had the advantage of very low dead capacity, high dielectric capacity, and easy filling for powdered solids and liquids.

A 2-mm. tungsten rod was plug-sealed into a B.24 ground-glass cone to support the centre electrode assembly. One end of this rod was brazed into the centre electrode, which was hollowed to lessen its weight and so reduce strain on the glass–metal seal. The tungsten rod served as the lead to the live electrode.

The outer electrode was built into a B.24 socket. Two A.7 sockets were sealed into the neck of this B.24 socket for filling and nitrogen protection. The electrode was silver-plated directly on to the glass. A platinum-wire seal brought the lead from this electrode through the glass. Spacing between the electrodes was 2 mm. The air capacity was found to be 28·6 pF and the loss factor negligibly small except at frequencies below 300 c/s.

Filling of the cell was accomplished with the precautions already described, aided by gentle tapping. This ensured complete filling around the bottom of the electrodes. For measurements at 20° or above, the cell was immersed in a liquid-paraffin bath thermostatically controlled. For lower temperatures a Dewar flask with ice–salt or alcohol–solid carbon dioxide mixtures was used. An alcohol thermometer was found to give sufficient accuracy in temperature measurement down to −40°.

Cell No. 3. A modification of the cell used by Holmes-Walker and Ubbelohde was employed for the measurements of conductivities and breakdown voltages. In order to reduce the effects

of intercrystalline resistances it is desirable to compress the powdered solid. Compressions of up to 20 kg./cm.^{2} were obtainable by loading the hollow chamber *A* with lead weights. A 7/16-in. stainless-steel rod attached to *A* formed the live electrode. The live lead was carried by the stainless-steel chamber *A* and associated support.

The lower electrode consisted of a short length of 7/16-in. stainless-steel rod with a platinum lead sealed through the glass. The thickness of sample contained within these electrodes was measured by means of a Pye travelling microscope. Filling was carried out by using the B.19 side arm.

Measurements from room temperature to 80° were made by immersing the electrode assembly in a small paraffin-bath fitted with an external heater fed from a Variac transformer. Temperature was recorded by using an ordinary thermometer.

In principle, polarisations *P* can be calculated from the dielectric constants of the solids. There are, however, difficulties in calculating molar polarisations from measurements on powders, owing to local variations of internal field arising from gaseous crevices and holes in the powder. In addition to corrections proposed for this effect by Böttcher (*loc. cit.*), non-spherical crystals of a substance with marked anisotropy of polarisability along the principal axes can give a packing of the powder which does not average the different orientations completely.

As a test, measurements of dielectric constants were made with powdered anthracene. When Böttcher's corrections are applied to these measurements, $P_{An} = 56{\cdot}2$ c.c. This compares with a mean molar refractivity for anthracene which is stated to be 62 c.c. Various attempts to increase randomisation of crystallisation in the powder, or filling the gas spaces by a fluid hydrocarbon (Nujol) gave no better agreement. It was therefore decided to treat the calculated polarisabilities by using Böttcher's corrections as relative values only; since the different complexes are likely to behave in a similar way, significant information can be derived from comparative results.

Dielectric constants of the powdered solids were measured by using the heterodyne-beat method. The true value of the dielectric constant ε_0 was obtained from the formula

$$(\varepsilon - 1)/(3\varepsilon) = V(\varepsilon_0 - 1)/(\varepsilon_0 + 2\varepsilon) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where *V* is the volume occupied by the crystals and ε is the dielectric constant of the particles (Böttcher, *loc. cit.*). Results are collected in Tables 1 and 2. Polarisations were calculated from

$$P = M(\varepsilon_0 - 1)/d(\varepsilon_0 + 2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

To test for the presence of temperature effects, measurements on selected solids were made at various temperatures from −40° to +40° maintained by manual control of a simple thermostat.

TABLE 1. *Dielectric constants ε_0 and polarisation P at 20°.*

Substance	Density (g./c.c.)	ε_0 (powdered solids)	*P* (c.c.)	ε_0 (suspension) in Nujol	Substance	Density (g./c.c.)	ε_0 (powdered solids)	*P* (c.c.)	ε_0 (suspension) in Nujol
Anthracene	1·150	2·71	56·2	2·59	$Na_{2\cdot12}An$ ...	1·347	5·38	99·6	—
$Na_{1\cdot30}An$ ...	1·290	3·00	64·5	2·79	$Li_{1\cdot31}An$ ...	1·165	2·77	59·6	—
$Na_{1\cdot76}An$ ...	1·329	3·10	67·5	2·90	$Li_{1\cdot65}An$ ...	1·619	2·78	60·5	—
$Na_{2\cdot00}An$ ...	1·355	3·18	69·5	2·95	$Li_{2\cdot00}An$ ...	1·173	2·80	61·4	—
$Na_{2\cdot05}An$ ...	1·349	3·70	79·4	—	$K_{2\cdot00}An$ ...	1·496	3·79	77·5	—

TABLE 2. *Variation of dielectric constant ε_0 with temperature.*

Substance	−40°	−20°	0°	+20°	+40°
$Na_{1\cdot30}An$	2·91	2·94	2·97	3·00	3·02
$Na_{2\cdot00}An$	3·10	3·11	3·15	3·18	3·21
$Na_{2\cdot05}An$	3·57	3·60	3·66	3·71	3·95

Dielectric Loss.—For the radio frequencies from 5×10^4 to 5×10^7 c/s the method of reactance variation in a tuned circuit (Hartshorn and Ward, *J. Inst. Elect. Eng.*, **1936**, **79**, 597) was used in a modified form. For frequencies in the range from 10^2 c/s to greater than 10^6 c/s a General Radio type **716—1** capacitance bridge was used, which gave direct reading in both capacitance and tan δ. A substitution method of evaluating the dielectric loss was used. Dielectric constants obtained were corrected by using equation (1). The variation of tan δ with frequency is shown in Fig. 2.

Conductivity Measurements.—Holmes-Walker and Ubbelohde measured the conductivities of complexes by direct galvanometer reading of the small current passed when a large potential

is applied to thin layers of the lightly compressed sample. This method has disadvantages in that voltage gradients of the order of 10^3 v/cm. must be used for the complexes under investigation to obtain a measurable current. In view of the comparatively low breakdown voltages now observed for the complexes, it was thought desirable to measure conductivities at lower voltage gradients. Use was made of a sensitive valve voltmeter incorporating six switched ranges between 0 and 100 v with constant input impedance of 11 megohms on all ranges. The resistance of the sample (in megohms) is given by

$$R = 11(V_A - V_B)/V_B \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where V_A is the applied voltage and V_B is the measured voltage after passing through the sample. Conductances of the alkali-metal–anthracenes are given in Table 3.

TABLE 3. *Conductance parameters of alkali-metal–anthracenes at* 20°.

(equation : $\log \sigma = \log \sigma_0 + E/kT$)

Substance	V_A (v)	σ (ohm^{-1} cm.$^{-1}$)	σ_0 (ohm^{-1} cm.$^{-1}$)	E (ev per molecule)
$Na_{1\cdot42}An$	220 *	$3\cdot51 \times 10^{-10}$	$5\cdot14 \times 10^{+10}$	1·16
$Na_{2\cdot05}An$	30	$1\cdot6 \times 10^{-9}$	$3\cdot61 \times 10^{+4}$	0·70
$Na_{2\cdot05}An$	60	$1\cdot65 \times 10^{-9}$	$3\cdot5 \times 10^{+4}$	0·68
$Na_{2\cdot12}An$	30	5×10^{-9}	$8\cdot9 \times 10^{+3}$	0·65
$Na_{2\cdot12}An$	60	$5\cdot7 \times 10^{-9}$	$8\cdot3 \times 10^{+3}$	0·63
$Na_{2\cdot12}An$	220	$6\cdot3 \times 10^{-9}$	$7\cdot4 \times 10^{+3}$	0·60

V_A is the voltage applied across the sample. In view of the low breakdown voltages it is interesting to note the slight change in σ with change in V_A. * Holmes-Walker and Ubbelohde, *loc. cit.*

Breakdown Voltages.—For reasons discussed by Daniel and Stark (*Trans. Faraday Soc.*, **1951, 47, 149**) the behaviour of the dielectric constant at low frequencies under D.C. polarising fields was though to be of interest. During these experiments indications were obtained of comparatively low breakdown voltages.

In order to obtain more accurate breakdown voltages, the E.H.T. voltage was applied directly to the cell with a sensitive milliamp-meter connected in series. The onset of breakdown or conduction could be detected by the sudden onset of current flowing through this meter. Difficulty was experienced in obtaining reproducible results owing to poor regulation of the radiofrequency E.H.T. voltage on load. Results recorded in Table 4 are accurate only to within several hundred volts/cm.

TABLE 4. *Breakdown voltages of alkali-metal–anthracenes at* 20°.

Substance	$Na_{1\cdot7}An$	$Na_{2\cdot0}An$	$Na_{2\cdot05}An$	$Na_{2\cdot12}An$
Breakdown voltage (kv/cm.)	11·4	9·1	6·1	5·3

DISCUSSION

Apart from information from magnetic measurements, which will not be further discussed here, three main lines of evidence about the nature of the bonding in these solid complexes can be discussed in the light of the experimental findings reported above.

Molar Volumes.—As pointed out previously (Holmes-Walker and Ubbelohde, *loc. cit.*), if the solid complexes approximate to close-packed ionic structures, the volume should be approximately the sum of the volume of the alkali-metal cation, and the anthracene anions. Though the volume of ions such as An^{2-} is not known, by analogy with other anions it is likely to be larger, but not much larger, than the volume of uncharged anthracene, as a result of electrostatic repulsive forces. The molar volume of the anthracene anions being written as (155·0 + Δ) c.c., where Δ is the enlargement due to the negative charges, the volume of a complex such as $(M^+)_2An^{2-}$ should be $V_{complex} = 2V_{M^+} + 155\cdot0 + \Delta$.

Here V_{M^+} is the volume of the positive cation $= \frac{4}{3}\pi r_+^3 N$, where r_+ is the radius of the cation in ionic structures and N is Avogadro's number. The new results permit a much more complete check of this hypothesis, since comparisons can be made between the cations Li^+, Na^+, K^+, which have very different sizes and also exert different electrostatic fields at their surfaces of contact with the anions. Relevant data for the complexes Li_2An, Na_2An, and K_2An are given in Table 5.

Several interesting conclusions emerge from these results. The fact that $V_{An^{2-}}$ (col. 5) is approximately the same in spite of the very different molar volumes of the complexes is in accordance with the hypothesis of structures approximating to close-packed ionic. At

TABLE 5. *Molar volumes of complexes* M_2An.

M	Ionic * radii (r_+, in Å)	$2V_{M^+}$ (c.c.)	$V_{complex}$ (obs.)	$V_{An^{2-}}$ if wholly ionic	Δ (c.c. per mole)	Shrinkage on formation from metal and hydrocarbon (c.c.)
Li	0·60	1·1	163·6	162·5	7·5	17·4
Na	0·95	4·35	165·6	161·25	6·25	37·1
K	1·35	11·95	171·3	159·35	4·35	74·4

* From Wells, " Structural Inorganic Chemistry," Oxford, 1950.

the same time, the differences in Δ are probably real. These differences are found both in the values for M_2An, and for M_xAn with $x < 2$ which give smooth plots as functions of x (Fig. 1). Evidence referred to in the next sections suggests that these complexes of intermediate composition are solid solutions. Reasons for supposing that electron transfer is not 100% complete even up to the composition M_2An are discussed further below.

In alkali-rich complexes, so far studied only for sodium, additional metal atoms beyond the composition M_2An cause far less shrinkage. Volume increments rapidly approach the closeness of packing in metallic sodium itself (Table 6).

Thermodynamic Evidence.—No complete exploration of the phase equilibria has yet proved possible. Evidence so far obtained suggests that homogeneous solid solutions are formed over the whole range of values of x in M_xAn. The partial molal free energy of

TABLE 6. *Molar volumes (c.c.) of* Na_xAn *with* $x > 2$ *(at 20°).*

		Increment (c.c.) over Na_2An :		
x	$M.V._{obs.}$	Obs.	calc. if Na is metal	calc. if Na is ion
2·08	166·7	1·1	1·9	0·35
2·12	168·3	2·7	2·85	0·53

removal of one or other of the components from the complex has still to be studied quantitatively but the following indications are significant.

(i) Anthracene can only be removed with difficulty from the solids, by sublimation, contrary to what would be expected if they consisted of hetero-crystalline mixtures of M_2An with anthracene. On elutriation with hot benzene, anthracene dissolves out progressively up to the composition M_2An, beyond which further removal in solution becomes very difficult. At ordinary temperatures around 20° the concentration of anthracene in equilibrium with M_xAn is about 0·5% (w/v), which is only one-sixth of the value for crystalline anthracene, again indicating solid solutions rather than a hetero-crystalline mixture.

(ii) On exposure of the complexes to the vapour pressure of sodium at 120°, a steady state is reached when $x \approx 2{\cdot}12$. This corresponds with very nearly one sodium atom in eight groups of Na_2An and may involve a new crystallographic packing.

Electrical Properties.—The solid complexes exhibit a range of rather special electrical properties, as may be expected on the basis of the interpretation that they consist of alkali-metal atoms dispersed in solid solution in the crystals of the aromatic hydrocarbon, with substantial but not complete transfer of electrons between alkali atoms and anthracene. Though no complete exploration of all these peculiarities has yet proved possible, the new findings permit certain leading conclusions to be made.

Electrical Polarisation of the Crystals.—From Table 2 it can be seen that the dielectric constant of the solid is practically independent of temperature over the range −40° to +40°. If the temperature coefficient had been similar to that found, *e.g.*, in solid hydrogen chloride above the " rotational " transition point (Böttcher, *loc. cit.*, p. 404), the value of ε at −40° would have decreased by about 10% at +40°. The inference is that in these complexes there is little or no freedom of orientation of any dipoles through the above range of temperatures. Actually there is a small increase in ε which may be due to increased polarisability at the larger molar volumes.

It is further noteworthy that the dielectric constant of the solids was found to be practically independent of the frequency from 50 Mc/s to 1 kc/s. Below about 1 kc/s there was a small increase (5%) in dielectric constant, possibly owing to a very small concentration of free ions in solid solution. By contrast, truly ionic crystals such as alkali

halides show a large increase on passing from the refractive index of about $n^2 = 2{\cdot}2$ to the static dielectric constant $\varepsilon \approx 7$.

As a further test for the absence of free ions, the dielectric constant at low frequencies (1 kc/s) was measured whilst applying a high polarising field, of about 10^4 v/cm. With an equimolecular hetero-crystalline mixture of sodium chloride and anthracene, application of the D.C. field led to a small but definite drop in ε as a result of this freezing of the free ions present (Daniel and Stark, *Trans. Faraday Soc.*, 1951, **47**, 149). With the complexes M_xAn on the other hand no change in ε could be observed when the D.C. field was applied.

From the measured dielectric constants, it was desirable to determine whether there was much change in polarisabilities resulting from the change,

$$2Na\ (gas) + anthracene \longrightarrow solid\ complex$$

since such changes would throw light on the nature of the bonding.

There are two main conclusions. First, on formation of the complexes in the process $2M_{gas} + An \longrightarrow M_2An$ there is a big decrease in polarisability corresponding with the big shrinkage in volume: $(P_{obs.} - 56{\cdot}2 - 2P_{M^+})$ is a large negative quantity.

On the other hand, it will be seen that if cation polarisabilities are used, the calculated P_{An}^{2-} though not wholly constant is reasonably consistent (Table 7). Much larger discrepancies would be obtained if atomic polarisabilities of the metal atoms were used as in the

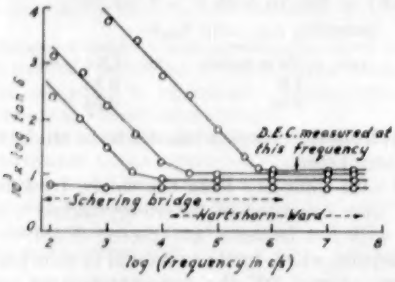


FIG. 3. *Dielectric loss for sodium complexes,* M_xAn.
Curves, from top to bottom: $Na_{2\cdot12}An$, $Na_{2\cdot0}An$, $Na_{1\cdot9}An$, anthracene.

last column. Just as for the calculations of molar volumes, the polarisabilities give definite support to the hypothesis of electron transfer from the alkali metal to the anthracene. The difference $\Delta_2 = P_{obs.} - (P_{An} + 2P_{M^+})$ is of the same order as the change on forming I^- from I atoms ($P_{I^-} - P_I = 5$ c.c.). As in the case of the molar volumes, the variation in Δ_2 with the different alkali-metal atoms is probably real, and arises from the fact that transfer is not 100% complete at the composition M_2An. With lithium the bonding is more covalent than with, *e.g.*, potassium, owing to the more electropositive nature of the latter. In this connection it is noteworthy that ionic anthracene An^{2-} is likely to have higher polarisability than a covalent-bonded dimetal addition product, because of the greater delocalisation of electrons in the ion An^{2-} or ion MAn^-.

TABLE 7. *Molar polarisations of complexes* M_2An *(c.c./mole).*

M	$P_{obs.}$	$2P_{M^+}$ *	$P_{An^{2-}}$ (if wholly ionic)	$\Delta_2 = P_{obs.} - (P_{An} + 2P_{M^+})$	$2P_M$ (gas)$^+$ *
Li	61·4	0·30	61·1	4·9	60·6
Na	69·5	0·97	68·5	12·3	121·6
K	77·5	4·54	73·0	16·8	171·0

* From Syrkin and Dyatkina, "Structure of Molecules," London, 1952.

TABLE 8. *Polarisation in* Na_xAn *with* $x > 2$ *(c.c. mole).*

x	$P_{obs.}$	ΔP	Calc. contribution if excess Na present as free atoms
2·00	69·5	0	—
2·08	79·4	9·9	4·9
2·12	99·6	30·1	7·3

A second striking conclusion is that there is a relatively enormous increase in polarisability in complexes with $x > 2$(Table 8). The increment ΔP is markedly greater than that

calculated for a dispersion of sodium atoms in Na_2An without any electron interaction. This agrees with the dark colour and general metalloid behaviour of these sodium-rich complexes, which begin to resemble alloys of electropositive metals with metalloid atoms.

Dielectric Loss.—Two loss mechanisms are indicated from a plot of log tan δ against log frequency (Fig. 3). A constant A.C. loss is evident for all the complexes with values of the order tan $\delta = 0{\cdot}010$. This compares closely with that for anthracene with measured tan $\delta = 0{\cdot}006$. The low value of loss is indicative of the absence of free or impurity ions, thus confirming the behaviour of the dielectric constant under polarising fields.

At low frequencies an abrupt change of slope to approximately 45° occurs. This is characteristic of D.C. conductivity. No corresponding increase in dielectric constant occurs, which shows that the conductivity is not of an ionic nature but must be electronic. This concurs with the observed increase in electron polarisation. The D.C. conductivity for complexes with $x < 2$ has already been examined by Holmes-Walker and Ubbelohde. Comparison of the observed losses and calculated losses by using $\delta = 2\pi$ f.c.r. with losses calculated from conductance values obtained by these workers shows fair agreement.

For the lowest frequencies (10^2 c/s), a slight tendency for the slope of the loss plot to decrease may be due to the limited ionic polarisation as suggested previously.

The absence of other loss phenomena is of interest. If complexes with $x < 2$ are regarded as dispersions of diluent hetero-crystalline anthracene in conducting crystals of M_2An, then a Maxwell–Wagner type absorption would be expected. The absence of such an absorption suggests that the excess of anthracene in such complexes is bound in some manner. Confirmation for this view is provided by electrostriction data. The evidence thus obtained agrees with the view that the excess of anthracene is distributed in the crystal to form a solid solution.

Dielectric Breakdown.—Comparatively low values of breakdown voltages of the order of 10^4 v/cm. were obtained for the alkali-metal complexes. This compares with values of 10^6 v/cm. for the alkali halides and with 6×10^3 v/cm. for powdered magnesium (Swann, Symp. on Static Electrification, *J. Appl. Phys.*, 1953).

Von Hippel (*Z. Physik*, **1936**, **98**, 580) and Coulson (" Valence," Oxford Univ. Press, 1951) have suggested that in an insulator in a high electric field a small number of electrons will leave one of the fully occupied bands and move into the conduction band. The resulting conduction will occur probably by an electron-avalanche mechanism. If the electrons from the alkali-metal atoms acquire a limited degree of mobility, as suggested earlier, then the low values of breakdown voltage may be explained. The solid solution is thought to consist of a giant assemblage of neutral and ionised alkali-metal atoms, and neutral and negative anthracene molecules. Finite, but not very large, activation energy appears to be required for the electrons to migrate from one anthracene molecule to the next. Holmes-Walker and Ubbelohde have found values of the order of 1 ev for complexes with $x < 2$. Bowen (*J. Chem. Phys.*, 1945, **1**, 1) has shown that " exciton " migration is quite extensive in the anthracene lattice. Clearly, the low breakdown voltages must be caused by the increased electron mobility in the complexes and by the low activation energies required for electron migration. More evidence for bonding of anthracene in complexes with $x < 2$ is provided by the small differences in breakdown voltage with variation in alkali-metal content x. If the excess of anthracene is present as diluent hetero-crystals in M_2An, a considerable increase in breakdown voltage might be expected.

D.C. Electrical Conductivities.—New results with a method less liable to give difficulties due to breakdown effects and on the sodium-rich complexes are summarised in Table 3. The sodium-rich complexes still exhibit a positive temperature coefficient of conductance, showing that the electrons have to be activated to pass into a conducting energy band. The activation energies are notably smaller than those previously measured, indicating that as the proportion of alkali-metal atoms to anthracene molecules in the crystal increases, it becomes easier to delocalise the electrons giving rise to conduction.

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Exchange Studies of Certain Chelate Compounds of the Transitional Metals. Part I. The Exchange of [^{14}C]Ethylenediamine with Certain "Labile" Metal–Ethylenediamine Complexes.

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The exchange, in aqueous solution, of [^{14}C]ethylenediamine between ethylenediamine (en) and the complex ions $[Zn\,en_3]^{2+}$, $[Cu\,en_2]^{2+}$, and $[Hg\,en_2]^{2+}$, was complete within five seconds at 0°. Under suitable concentration conditions, the exchange with the $[Ni\,en_3]^{2+}$ ion was discernible at 0°, with $t_{\frac{1}{2}}$ exchange ~5 seconds. The general features of the latter exchange were elucidated and an approximate rate constant was obtained. The dissociation of the first ethylenediamine from the $[Ni\,en_3]^{2+}$ ion was shown to be faster in acid than in alkaline solution.

Most of the work on the isotopic exchange of metal ions and of ligands with complex ions in aqueous solution has been qualitative. The immeasurably fast or very slow exchanges observed could, in most cases, be understood from a consideration of the chemical properties of the complex ions or even from a knowledge of the detailed electronic structure of the ion, especially in the case of octahedral complexes (Taube, *Chem. Rev.*, 1950, **50**, 69). Although some of these results were important, there was a need to study systems which would give measurable rates; and, recently, detailed kinetic studies of both four- and six-co-ordinated complexes have been described. These have usually been carried out by using labelled ligands rather than metal ions. Exchange of the latter, M^{m+} with (say) $MA_6^{n\pm}$ will, unfortunately, be accompanied almost always by interaction between these exchanging species, with the formation of all the possible intermediate ions in amounts governed by the successive formation constants of the system. This interaction may lead to theoretical and practical difficulties. The limited number of complex systems not behaving in this way are of two types: (*a*) complex ions which can co-exist with a substantial amount of metal ion without the formation of appreciable amounts of intermediate complex ions, because of their relatively small stability, and (*b*) the case where A_6 is one hexadentate molecule. An example of the former class is the ion $[Fe(o\text{-phenanthroline})_3]^{2+}$, exchange of which with ferrous ion has been examined by Whitney, Schweitzer, and Comar (*J. Amer. Chem. Soc.*, 1955, **77**, 1390); and for the latter type (*b*) Jones and Long (*J. Phys. Chem.*, 1952, **56**, 25), for example, studied the exchange of $[FeY]^-$ with ferric ion (Y = ethylenediaminetetra-acetate ion). The complication mentioned above does not arise with ligand exchange, and the only drawback to its use is the certain amount of difficulty accompanying the preparation of the ligand (especially if organic) suitably labelled.

Ethylenediamine ($NH_2{\cdot}CH_2{\cdot}CH_2{\cdot}NH_2$ = en) forms a large number of metal complexes several of which might, considering their properties and stereochemistry, exchange at measurable rates with ethylenediamine. [^{14}C]Ethylenediamine was synthesised (Popplewell and Wilkins, *J.*, 1955, 2521) and this paper is concerned with its exchange with certain "labile" complexes, these being ones which undergo substitution reactions rapidly and are complete in about one minute under ordinary conditions (Taube, *loc. cit.*). The definite rate of exchange observed with the nickel complex ion, $[Ni\,en_3]^{2+}$, in alkaline solution at 0°, encouraged us to study the $[Zn\,en_3]^{2+}$, $[Hg\,en_2]^{2+}$, and $[Cu\,en_2]^{2+}$ ions, under similar conditions, but unfortunately these exchanged at immeasurably fast rates. From the exchange rates an approximate dissociative rate constant was determined for the $[Ni\,en_3]^{2+}$ ion and it was possible to compare this with dissociative rates of the same ion in acid medium (cf. Bjerrum and Poulsen, *Nature*, 1952, **169**, 463).

Work is continuing on the exchange behaviour of certain "inert" metal–ethylenediamine complex compounds (for a preliminary survey of results, see Popplewell and Wilkins, Report on International Conference on Co-ordination Compounds, Amsterdam, 1955, *Rec. Trav. chim.*, to be published) and of phenanthroline–metal complexes containing [^{14}C]phenanthroline.

Experimental

Preparation of [^{14}C]*Ethylenediamine and* [^{14}C]*Ethylenediamine Dinitrate.*—The dihydrochloride was prepared as already described (Popplewell and Wilkins, *J.*, *loc. cit.*). A solution of the free [^{14}C]base in water was obtained by passing an aqueous solution of the salt through the hydroxy-form of an anionic exchange resin (Amberlite IRA-400). [^{14}C]Ethylenediamine dinitrate was obtained in almost quantitative yield by dissolving the dihydrochloride in the least amount of hot saturated lithium nitrate solution, adding alcohol, and cooling. The product was well washed with alcohol and found to be lithium- and chloride-free. The dihydrochloride was used to afford active complexes as described below.

Preparation of the Complexes.—The perchlorates were used in all exchange studies to obviate the possibility of induced anionic exchange. The exchange of $[Au\ en_2]^{3+}$ ion, for example, is accelerated by the addition of chloride ion (Popplewell and Wilkins, *Rec. Trav. chim., loc. cit.*). Trisethylenediaminenickel(II) perchlorate was prepared from the chloride (Werner, *Z. anorg. Chem.*, 1899, **21**, 201) by addition of excess of sodium perchlorate in concentrated aqueous solution. It was recrystallised several times from water (Found : Ni, 13·5; en, 41·1. Calc. for $C_6H_{24}O_8N_6Cl_2Ni$: Ni, 13·4; en, 41·1%).

Trisethylenediaminezinc(II) perchlorate was prepared from the corresponding chloride (*idem, loc. cit.*) in a similar way to the nickel analogue (Found : Zn, 14·8; en, 40·4. Calc. for $C_6H_{24}O_8N_6Cl_2Zn$: Zn, 14·7; en, 40·55%).

Bisethylenediaminecopper(II) perchlorate was prepared from the corresponding chloride and recrystallised several times from water. The substance was anhydrous (Found : Cu, 16·7, 16·8; en, 31·2. Calc. for $C_4H_{16}O_8N_4Cl_2Cu$: Cu, 16·6; en, 31·4%). Lange (*Ber.*, 1926, **59**, 2107) reports it as a hemihydrate.

Bisethylenediaminemercury(II) perchlorate was prepared as described by Pfeiffer, Schmitz, and Böhm (*Z. anorg. Chem.*, 1952, **270**, 287), and recrystallised several times from water (Found : en, 23·2. Calc. for $C_4H_{16}O_8N_4Cl_2Hg$: en, 23·15%).

In all cases samples of the complexes containing [^{14}C]ethylenediamine and of suitable activity for the exchange experiments were most conveniently prepared by heating the pure inactive complex perchlorate (10 parts) with [^{14}C]ethylenediamine dihydrochloride (1 part) for a short while in a hot almost saturated solution and allowing the complex perchlorate to crystallise on cooling. In most cases the active complex was recrystallised a further time. In the case of the bisethylenediaminemercury(II) compound the small amount of the insoluble chloride which separated on addition of the dihydrochloride was filtered off in the hot before the perchlorate crystallised out on cooling.

Ethylenediamine was purified by storage over sodium hydroxide and distillation twice from fresh potassium hydroxide, the fraction of b. p. 117·3—117·4° being collected. Methyl alcohol was dried by reaction with magnesium and subsequent distillation from magnesium perchlorate.

Analyses.—For the nickel, zinc, and mercury complexes, the bound ethylenediamine was estimated (in the same way as was the free base) by direct titration with standard acid using bromocresol-green as indicator. With the copper compound we observed, like Johnson and Bryant (*J.*, 1934, 1783), that direct titration in this way did not give a sharp end-point, even by potentiometric titration, and the estimation was best carried out by adding a known excess of standard perchloric acid to a dilute solution of the copper complex (destroying the colour) and back-titrating with standard alkali until the first appearance of a blue colour, owing to the re-formation of a small amount of the intensely coloured copper–ethylenediamine complex. Analyses for the metal were carried out by standard methods (usually gravimetric).

Counting Procedure.—Counting was carried out on almost " infinitely thick " samples; the measured activity (in counts/min.) is then proportional to the specific activity of the material. The samples, of reproducible composition in any particular run, were prepared essentially as described by Adamson and Wilkins (*J. Amer. Chem. Soc.*, 1954, **76**, 3379) except that the cylindrical depression machined out of a thick aluminium disc was 1·0 cm. in diameter. The amount of material in this area of " mat " corresponding to an " infinite thickness " is about 22 mg. (Libby, *Analyt. Chem.*, 1947, **19**, 2) and is almost independent of the composition of the ^{14}C-containing material. Mats of 15—20 mg. were usually prepared; the variation of count with these amounts of material was very small. A series of tests of a standard substance were carried out and gave reproducibility of counting of about 4%. Samples were counted for a total of about 2500 counts (2% statistical accuracy). Standard electronic equipment was used in conjunction with a G.E.C. mica end-window counter and a Panax Universal lead castle. The usual allowance was made for background (about 11 counts/min.).

Exchange Experiments.—In all cases the complex was separated from the ethylenediamine in aqueous solution by precipitation with a large anion, *e.g.*, HgI_4^{2-}, $PtCl_4^{2-}$, or $S_2O_3^{2-}$. Usually in each system studied, appearance of activity in the initially inactive complex and disappearance in the initially active complex were observed. The exchanges were carried out in a simple apparatus described by Rich and Taube (*J. Phys. Chem.*, 1954, **58**, 1). In one compartment of a flask was placed an aqueous solution of the complex and in the other compartment an aqueous solution of ethylenediamine (in boiled-out distilled water). The two solutions in the flask were then immersed in a large Dewar flask containing ice and water and left for 10—15 min. After this time, the two solutions were rapidly mixed by shaking the vessel vigorously from side to side (zero time). An ice-cold solution of the precipitant was added almost immediately afterwards (when very early exchange times were required) and the time of exchange taken at the point of copious precipitation which in most cases appeared instantaneously. The precipitated complex was quickly centrifuged, and washed once with cold water, twice with alcohol, and twice with ether. It was dried in the air for 20 min., and then at 60° for 5 min. The distribution of activity between the exchanging species was that expected, within experimental error, from the equivalents of ethylenediamine in the complex and in the added ethylenediamine. The molarities of ethylenediamine recorded represent the total amount of species [en], $[enH^+]$, and $[enH_2^{2+}]$, present at the pH of the experiment. All measurements were carried out at 0°. Because of the nature of the experiments no attempt was made to maintain a constant ionic strength. Some exchanges were carried out in the dark with no different results.

Acid Dissociation Experiments.—These were carried out in the same way as the exchange experiments with a solution of the complex in one compartment and an excess of aqueous perchloric acid in the other.

Exchange of $[Ni\,en_3]^{2+}$ *Ion.*—Typical results are given in Table 1. These are rather fully tabulated in order to give some idea of the accuracy and reproducibility of the experiments.

TABLE 1. *Exchange of* $[Ni\,en_3]^{2+}$ *with ethylenediamine at* 0°.

Run no.	1	2	3	4	5
$10^2 \times$ Molarity of complex	5·5	5·3	5·3	51·3	4·6
$10^2 \times$ Molarity of ethylenediamine	0·93	1·0	15·74	153·7	147·3
Approx. pH of mixture	10·0	11·4	10·9	11·4	11·4
Original activity of complex (counts/min.)	0	0	353	349	406
Activity of complex (counts/min.) after various times (sec.)	125(5·1)	200(3)	296(2·8)	296(2·8)	197(5·7)
	127(5·2)	203(300)	266(3·4)	248(3·6)	183(7·0)
	120(8·3)	—	258(6·0)	269(4·0)	151(10·3)
	127(14·8)	—	159(60)	248(6·3)	137(12·0)
				173(120)	26(120)
$t_{\frac{1}{2}}$ exch. (sec.)	<1	<1	~6	~5	~10
$10k_1$ (sec.$^{-1}$)	>1·1	>1·2	1·7	2·1	1·9
10^2k_2 (sec.$^{-1}$ mole^{-1} l.)	>2·0	>2·0	3·1	3·8	3·4
k_2 " "	>127	>127	13·1	1·43	1·37

Usually two or more runs were carried out for a particular condition of exchange (as was the case for the other systems studied) and reasonable agreement as to the order of half-life of exchange, $t_{\frac{1}{2}}$ exch., obtained, *i.e.*, <1, ~5, or ~10 sec. In some cases samples from different preparations were used, with similar exchange behaviour. The complex was precipitated and counted as the insoluble salt $[Ni\,en_3][PtCl_4]$. Sodium chloroplatinite solutions were used as the precipitant, freshly prepared because of the fairly rapid hydrolysis of the $PtCl_4^{2-}$ ion, which might lead to the precipitation of hydroxy-chloroplatinites of irreproducible composition. Similar results were obtained when precipitation of $[Ni\,en_3]S_2O_3$ was used as the separation procedure, and when the activity was in the ethylenediamine rather than in the complex at the commencement of the experiment.

Basolo and Murmann (*J. Amer. Chem. Soc.*, 1952, **74**, 5243) have measured the formation constants, $K_n = [ML_n]/[ML_{n-1}][L]$, for the nickel–ethylenediamine system at 0° and report $\log K_1 = 7{\cdot}92$, $\log K_2 = 6{\cdot}77$, and $\log K_3 = 5{\cdot}36$. By using these values and the measured pH of the complex solution before mixing with the ethylenediamine, it can be shown that the tris-species $[Ni\,en_3]^{2+}$ was present before mixing to the extent of 90% or more in all exchange runs. After the mixing, the nickel was present almost entirely as the tris-species. This means that a small amount of bis-species $[Ni\,en_2(H_2O)_2]^{2+}$ will be *very* rapidly converted into the tris-species during the mixing (since the formation rates are much faster than the dissociative rates) which

will lead to a small amount of induced exchange (Runs 3 and 5). In Runs 3, 4, and 5, extrapolation of the log (1 − fraction exchange)/time plot (Wahl and Bonner, " Radioactivity Applied to Chemistry," Chapman and Hall, Ltd., London, 1951, p. 16) gave zero-time induced exchanges of the order 15—25%.

For a dissociative mechanism, the rate of exchange, $R = k_1$[complex], or (more probably) $R = k_2$[complex][H_2O]. In addition, irrespective of the mechanism,

$$R = \frac{0{\cdot}693}{t_{\frac{1}{2}}\text{ exch.}} \cdot \frac{3[\text{complex}][\text{en} + \text{enH}^+ + \text{enH}_2^{2+}]}{3[\text{complex}] + [\text{en} + \text{enH}^+ + \text{enH}_2^{2+}]}$$

(see Wahl and Bonner, *op. cit.*, pp. 7 *et seq.*). The factor 3 arises from the presence of three equally exchangeable ethylenediamine molecules in the nickel complex. Therefore k_1 (and k_2) can be determined from the values of the half-lives of the exchange under different conditions (see Table 1).

On the other hand, for an S_N2 associative mechanism involving ethylenediamine species,

$$R = k_3[\text{complex}][\text{en}] + k_4[\text{complex}][\text{enH}^+] + k_5[\text{complex}][\text{enH}_2^{2+}]$$

If it is assumed that the second and third paths for exchange are much less important than the first (both species involved are positively charged ions and the concentration of enH_2^{2+} at the pH of the experiments extremely small), then $R = k_3$[complex][en] and k_3 can be calculated in the same way as k_1 and k_2. The value $pK_{enH^+} = 10{\cdot}73$ at 0° (Basolo and Murmann, *loc. cit.*) was used in estimating the concentration of free base.

The reasonable constancy of k_1 (and k_2) but not of k_3 under the different conditions strongly suggests that the mechanism of exchange is a dissociative one (or an associative process involving a water molecule) as would be expected. The general variation of $t_{\frac{1}{2}}$ exch. with the relative concentration of exchanging species supports this idea even if the simplifying assumption made above is not strictly valid.

Exchange of Other Labile Ions.—In all cases examined here exchange was complete within the times of separation (which were in some cases as low as 3 sec.). The measurement of the exchange of the $[Zn\,en_3]^{2+}$ ion had to be approached in a different way from that of the analogous $[Ni\,en_3]^{2+}$ ion. A solution prepared from $6{\cdot}7 \times 10^{-3}$ mmol. of the solid $[Zn\,en_3](ClO_4)_2$ dissolved in 1 ml. of solution contains less than 20% of the tris-species, $[Zn\,en_3]^{2+}$, and even at much higher concentrations the tris-species will hardly be the dominant species in solution. This arises from the relatively low value of K_3 for the zinc–ethylenediamine system ($\log K_1 = 5{\cdot}92$, $\log K_2 = 5{\cdot}15$, and $\log K_3 = 1{\cdot}86$, at 25°; Bjerrum and Anderson, *Kgl. danske Videnskab. Selskab, Mat.-fys. Medd.*, **1945**, **22**, **1773**). Consequently free inactive ethylenediamine was added to a solution of the active solid sufficient to ensure predominance of the tris-species (>85%), and the exchange of this mixture with inactive ethylenediamine studied in the usual way. Basolo and Murmann (*loc. cit.*) report values for the copper–ethylenediamine system at 0° ($\log K_1 = 11{\cdot}34$ and $\log K_2 = 9{\cdot}95$). The successive formation constants of the mercury(II)–ethylenediamine complexes being assumed to be of a similar order (only $\log K_1K_2 = 23{\cdot}42$ has been measured; Bjerrum, *Chem. Rev.*, **1950**, **46**, **381**), then under the conditions indicated in the Table $[Hg\,en_2]^{2+}$ and $[Cu\,en_2]^{2+}$ are the dominant species in solution.

In all cases the complex ions were separated from the ethylenediamine by precipitation as the $[HgI_4]^{2-}$ salt.

TABLE 2. *Exchange of* $[Zn\,en_3]^{2+}$, $[Cu\,en_2]^{2+}$, *and* $[Hg\,en_2]^{2+}$ *with ethylenediamine at* 0°.

Compound	Zn	Cu		Hg
$10^3 \times$ Molarity of complex	26·5	12·0	21·5	6·0
$10^3 \times$ Molarity of ethylenediamine	159·5	24·0	40·4	11·9
Original activity of complex (counts/min.)	500	271	0	162
Activity of complex (counts/min.) after various times (sec.)	166(6·0)	151(2·5)	205(5)	82(6·5)
	173(120)	147(4·0)	209(15)	82(39)
	—	151(120)	—	81(120)

Discussion

The only two exchange studies that have previously been reported with the complex ions studied in this paper involve the trisethylenediaminenickel(II) ion. The exchange of nickel between this ion and the aquated nickel ion (Johnson and Hall, *J. Amer. Chem. Soc.*, **1948**, **70**, **2344**), or the tetracyanonickelate ion at pH 9—11 (Long, *ibid.*, **1951**, **73**, **537**), was

shown to be extremely fast in water at room temperature. In agreement with these observations, the exchange of ethylenediamine with the $[Ni\,en_3]^{2+}$ ion in water is immeasurably fast at 20° even under the more favourable conditions (comparable rates of concentrations of exchanging species, see Table 1, Runs 3 and 4 at 0°). However a definite rate of exchange is observed if the temperature is reduced to 0°. The simple apparatus used to follow the exchange precluded the measurement of accurate rate constants, but the results almost certainly show that exchange takes place by a dissociative mechanism and that a bimolecular path involving the complex ion and an ethylenediamine species is not important. The dissociation of *one* ethylenediamine from the tris-complex leads to exchange when the ligand is labelled. This process is *very fast* in acid pH at 0°. This is easily shown by the fact that the lilac $[Ni\,en_3]^{2+}$ ion with excess of acid " instantly " becomes blue, forming the $[Ni\,en_2(H_2O)_2]^{2+}$ ion, but then more slowly becomes green, $[Ni(H_2O)_6]^{2+}$, the latter process occupying some seconds. The rate of dissociation of the first ethylenediamine from the tris-complex is therefore much slower at alkaline than at acid pH.

Bjerrum, Poulsen, and Poulsen (" Proceedings of the Symposium on Co-ordination Chemistry," Danish Chemical Society, 1954, p. 51) have measured the successive formation and dissociation rate constants of the three nickel–ethylenediamine complex ions (among others) in methanol at low temperatures. Extrapolation of the values obtained to 0° by Bjerrum (using determined activation energies) gave $[Ni\,en_3]^{2+} \longrightarrow [Ni\,en_2]^{2+}$, $\log k_{-3} = +0{\cdot}9$ sec.$^{-1}$; $[Ni\,en_2]^{2+} \longrightarrow [Ni\,en]^{2+}$, $\log k_{-2} = -0{\cdot}2$ sec.$^{-1}$; $[Ni\,en]^{2+} \longrightarrow Ni^{2+}$, $\log k_{-1} = -1{\cdot}0$ sec.$^{-1}$. As in water, dissociation of the higher complexes in acid methanol proceeds faster than that of the lower complexes. Exchange studies in methanol proved unsatisfactory. At low temperatures the crystal growth of the precipitated complex, after separation, was slow, leading to a certain amount of heterogeneous exchange and a poor separation procedure. At all temperatures there was a large induced exchange (30—35%) and this was not very reproducible. Some results at 0° indicate a rate of exchange $R = 9{\cdot}2 \times 10^{-5}$ sec.$^{-1}$ mole^{-1} l. ($3{\cdot}34 \times 10^{-3}$M-complex, $11{\cdot}3 \times 10^{-3}$M-ethylenediamine, $t_{\frac{1}{2}} = 40$ sec.), showing that dissociation is slower in methanol than in water, at alkaline pH. It is interesting that Basolo, Hayes, and Neumann (*J. Amer. Chem. Soc.*, 1953, **75**, 5102) have shown that it is the *first* dissociation of the trisphenanthroline- and trisdipyridylnickel(II) ions in acid which is the *slow* step, and that the subsequent steps are the faster ones.

The exchange of the analogous zinc ion, $[Zn\,en_3]^{2+}$, with ethylenediamine is complete in water within five seconds, thus establishing the enhanced lability of this ion compared with the $[Ni\,en_3]^{2+}$ ion. The result, in addition, provides excellent support for the rapidity of mixing by the simple method used in the exchange experiments. In view of these results and of the chemical properties of the nickel- and zinc–ethylenediamine ions, it is difficult to understand that, whereas attempts to resolve the $[Ni\,en_3]^{2+}$ ion have proved unsuccessful (Bucknall and Wardlaw, *J.*, 1928, 2739), the resolution of the $[Zn\,en_3]^{2+}$ ion has been reported (Neogi and Mukherjee, *J. Indian Chem. Soc.*, 1934, **11**, 681).

Finally both bisethylenediamine complexes investigated also exchanged too rapidly to be studied. The " immediate " disappearance of the deep-blue colour of the $[Cu\,en_2]^{2+}$ ion on addition of excess of acid at 0° indicates that the dissociative path for exchange would probably be very rapid even in alkaline solution. Bjerrum, Poulsen, and Poulsen (*loc. cit.*) report that for this ion dissociation rates in methanol show a marked dependence on acidity. In addition it might be expected that a bimolecular path would be important for the planar $[Cu\,en_2]^{2+}$ ion since a fifth position is readily available for attachment of an ethylenediamine molecule in a transition state {although the thermodynamic tendency of a third molecule of ethylenediamine to attach itself to the $[Cu\,en_2]^{2+}$ ion is very small, (Bjerrum and Nielsen, *Acta Chem. Scand.*, 1948, **2**, 297)}. Although there are indications of the existence of $[Hg\,en_3]^{2+}$ ions in solution, attempts to isolate the solid have been unsuccessful (see, for example, O'Brien, *J. Amer. Chem. Soc.*, 1948, **70**, 2771).

Nickel complexes with higher polydentate amines also dissociate rapidly. For example, Mann and Pope (*J.*, 1926, 482) report that the colour of $[Ni\,tren]^{2+}$ disappears immediately on addition of hydrochloric acid (tren = triaminotriethylamine, a quadridentate ligand). It appears that the only exception is the $[Ni(tetrameen)_2]^{2+}$ ion (tetrameen = tetra-*C*-methylethylenediamine) which dissociates in acid solution at a measurable rate ($t_{\frac{1}{2}} \sim 142$ sec.

at 25°; Basolo, Chen, and Murmann, *J. Amer. Chem. Soc.*, 1954, **76**, 956). Since the monotetraminenickel(II) ion is unstable, the exchange of the bistetraminenickel(II) ion with nickel ion should not be complicated by mutual interaction (see p. 4098) and should proceed at a measurable rate.

We thank the Department of Scientific and Industrial Research for a Maintenance Allowance (to D. S. P.), also Professor A. W. Adamson and Dr. H. S. Rossotti for a helpful discussion.

THE UNIVERSITY, SHEFFIELD. [*Received, June 27th*, 1955.]

Adsorption from Binary Liquid Mixtures: Some Effects of Ash in Commercial Charcoal.

By A. BLACKBURN and J. J. KIPLING.

[Reprint Order No. 6603.]

Commercial coconut-shell charcoals contain ash which may react with, or be dissolved by, organic liquids. This interferes with the measurement of physical adsorption from mixtures containing such liquids. Adsorption of the corresponding vapours may also be affected. Three simple ways of removing ash from these charcoals are examined. The effect of progressive removal of ash on adsorption from mixtures of benzene and acetic acid is considered in detail.

MOST commercial charcoals contain significant amounts of inorganic material, usually referred to as ash. This has rarely been regarded as important in the study of vapour-phase (physical) adsorption, but may interfere in experiments on adsorption from solutions. The point has long been realised for adsorption of electrolytes, as the components of the ash are themselves electrolytes, but little attention has been paid to effects obtained with solutions of non-electrolytes, or of substances such as acetic acid, which are adsorbed in non-ionised form by a charcoal surface, though they react as electrolytes with inorganic materials and in aqueous solution (Kipling, *J.*, 1948, 1483). In each of the last two cases, dissolution of ash may seriously alter the results of titrimetric or refractometric analysis of solutions, in which the observed changes in concentration are normally taken to be due to physical adsorption only.

A most important warning occurs in a paper by Garner and Kingman (*Trans. Faraday Soc.*, 1929, **25**, 24), who showed that very careful removal of ash from Norite charcoal was needed before interferometric analysis gave reliable results in adsorption from aqueous solutions of alcohols. Innes and Rowley (*J. Phys. Colloid Chem.*, 1947, **51**, 1172) found that methyl alcohol extracted sodium and potassium chlorides from their charcoal, and Blackburn and Kipling found that both acetone and acetic acid extracted ash from coconut-shell charcoal (*J.*, 1954, 3819; 1955, 1493). An example of interference with vapour-phase studies is given by Coolidge (*J. Amer. Chem. Soc.*, 1927, **49**, 708) who found that sulphur dioxide was permanently adsorbed by alkaline ash.

These effects can be avoided by the use of ashless sugar charcoals. It is, however, interesting to examine how easily ash can be removed from commercial charcoals, and how far industrial practice is likely to be affected if they are used untreated. We have therefore examined a commercial coconut-shell charcoal (*a*) as received, (*b*) after Soxhlet extraction with distilled water, (*c*) after extraction with acetic acid, followed by washing with distilled water, and (*d*) after extraction with hydrofluoric acid by Korver's method (*Chem. Weekblad*, 1950, **46**, 301), again followed by washing with distilled water. As we became aware of the last method after most of the work had been concluded we have done only a little work on charcoal (*d*). The method is interesting in requiring no more than that the charcoal be allowed to stand under aqueous hydrofluoric acid for a few days at room temperature.

The amounts of ash **1**, **2**, **3**, and **4** from the four charcoals *a*, *b*, *c*, and *d* were respectively 4·3, 3·1, 1·7, and 0·2%.

Ash 1 was a coarse, greenish powder which strongly attacked the glaze of the porcelain crucible in which the ashing was carried out. Ashes 2, 3, and 4 were fine, straw-coloured powders, which did not attack the glaze. In relation to the reported composition of charcoal ash (*e.g.*, Long and Sykes, *J. Chim. phys.*, 1950, **47**, 361, cf. figures for uncarbonised nutshell given by Tendolkar and Thakoor, *J. Sci. Ind. Res., India*, 1952, **11**, *B*, 501) it seems that water extracts mainly the compounds of the alkali metals, that acetic acid further extracts those of the alkaline-earth metals and iron, and that cold hydrofluoric acid extracts most of the remainder.

The effects of the three extractions on adsorption from solution have been examined in relation to the system benzene–acetic acid. This system has already been studied by Kipling and Tester (*J.*, 1952, 4123) who thought that the results were being affected by the presence of ash. Fig. 1 shows that the untreated charcoal has a significant effect on the refractive index of the acetic acid alone. This clearly affects refractometric analysis of mixtures even though the ash has no effect on benzene. The effect becomes the more

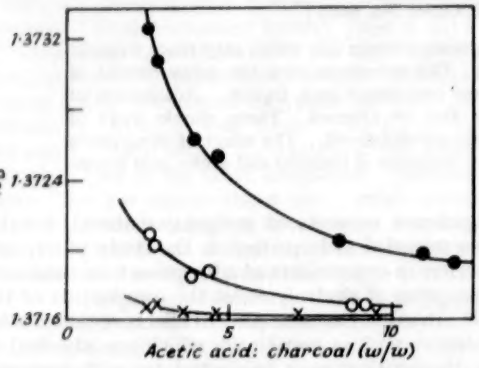


FIG. 1. *Effect of charcoals on the refractive index of acetic acid.*
n_D^{20} for pure acetic acid: 1·3716

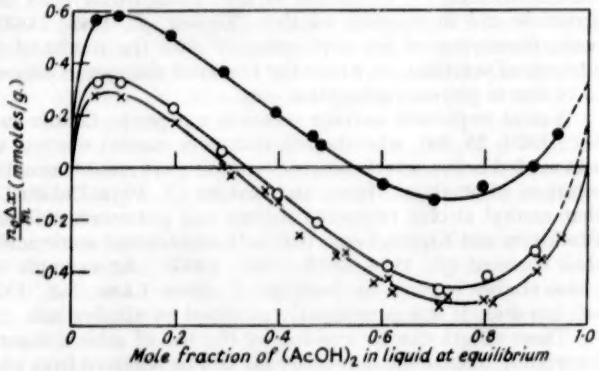


FIG. 2. *Isotherms of concentration change for the system benzene–acetic acid.*

For all Figs., ● = charcoal (*a*); ○ = charcoal (*b*); × = charcoal (*c*); □ = charcoal (*d*)

serious the higher the ratio of charcoal to acid. It is largely eliminated by washing the charcoal with water and almost completely eliminated by washing with acetic acid.

The effect on the isotherm of concentration change for this system is shown in Fig. 2. The position of the isotherm clearly depends on the amount of ash left in the charcoal. This has been emphasised in Fig. 2 by the use of a high ratio of charcoal to liquid for the untreated charcoal (about 1 g. of charcoal to 4 g. of liquid). The isotherm therefore differs from that published by Kipling and Tester in which the ratio was about 1 g. of charcoal to 20 g. of liquid. By contrast, there is only a small separation between the isotherms for the charcoals extracted with water and acetic acid respectively.

The two upper curves in Fig. 2 show two points of intersection with the concentration axis (*i.e.*, two points of zero selectivity). All previous experience shows that physical adsorption from such systems can give rise only to S- or U-shaped curves (one or no point of intersection), showing zero change in concentration when adsorption takes place from each pure component. The third curve is normal in this respect. It is clear that the extra point of intersection shown by the first two curves arises from the added effect of interaction between acetic acid and ash. The effect of ash in this respect vitiates several reported studies of liquid-phase adsorption, *e.g.*, that on the system toluene–acetic acid (Kane and Jatkar, *J. Indian Inst. Sci.*, 1938, **21**, *A*, 331); the isotherms, besides showing

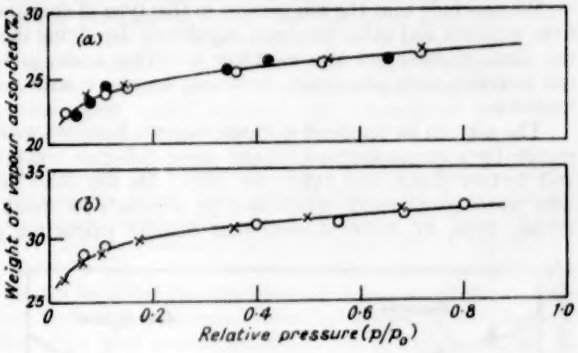


FIG. 3.
(*a*) *Adsorption of benzene vapour.*
(*b*) *Adsorption of pyridine vapour.*

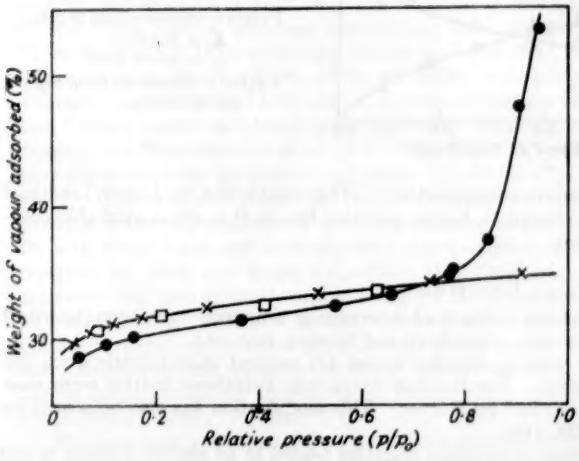


FIG. 4. *Adsorption of acetic acid vapour.*

more than one point of intersection, varied with the ratio of charcoal to liquid used, and it was admitted that the charcoal contained much ash. Similarly the isotherms obtained by Dobine (*Compt. rend.*, 1941, **212**, 156) for the system acetic acid–water show a concentration change at 100% acetic acid; this again was almost certainly due to dissolution of ash.

A related effect is found in the adsorption of vapours. Figs. 3*a* and *b*, showing the adsorption of benzene and of pyridine, suggest that the extraction processes do not significantly alter the surface area of the charcoal. Furthermore, the ash appears to be indifferent to benzene (which would be expected) and the water-insoluble ash is indifferent also to pyridine, which, as a base, could react with acidic or amphoteric ash. It may be assumed that the highly basic water-soluble ash will not react with pyridine. By contrast, the ash has a profound effect on adsorption of acetic acid, particularly at high

relative pressures (Fig. 4). On the treated charcoals, the isotherms are of the Langmuir type usually found for adsorption of organic substances on this charcoal.

In Fig. 5 we present the individual isotherms for adsorption from mixtures, both vapour and liquid, of benzene and acetic acid. These are of the general shape given by Kipling and Tester, but are now corrected for the effect of ash. It has been assumed that the acetic acid is adsorbed essentially in the form of dimeric molecules (cf. Blackburn and Kipling, *loc. cit.*, 1955).

Finally, we have found that charcoal extracted with hydrofluoric acid gave the same isotherm for adsorption from acetic acid–water mixtures as charcoal extracted with acetic acid (Blackburn and Kipling, *loc. cit.*).

We conclude that the ash present in this type of charcoal may interfere with adsorption from aqueous and other mixtures capable of dissolving inorganic salts, especially those of the alkali metals, and also mixtures involving acids, as the ash is basic. The ash does not interfere with adsorption involving bases, or with substances in which the ash is insoluble.

The ash can be removed in three stages. Korver's method gives the most satisfactory results for a simple method, though more elaborate treatment can reduce the ash content still further (Long and Sykes, *loc. cit.*). On the other hand, simple Soxhlet extraction with water gives results which may be adequate for many purposes [Reyerson (*Ind. Eng. Chem.*, 1925, **17**, 1114) showed that Soxhlet extraction removes most of the inorganic

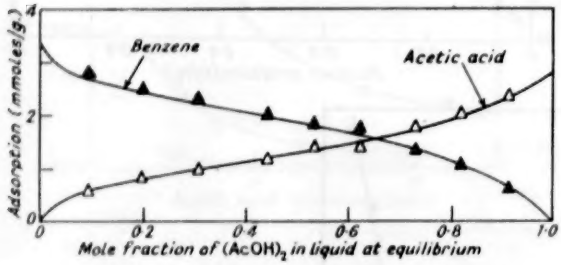


FIG. 5. *Individual isotherms for adsorption from the system benzene–acetic acid.*

Points: vapour-phase results;
▲ = benzene.
△ = acetic acid.

Curves: calculated from liquid-phase results.

matter from the coconut-shell before carbonisation]. This might also be a useful method of producing relatively ash-free charcoals, but in practice the shell is often available commercially only in carbonised form.

EXPERIMENTAL

The coconut-shell charcoal and the methods of determining isotherms have been described previously (Kipling and Tester, *loc. cit.*; Blackburn and Kipling, *locc. cit.*).

Extractions were carried out with (i) distilled water, (ii) purified glacial acetic acid, (iii) "AnalaR" hydrofluoric acid (40%). For the last extraction Polythene bottles were used rather than the waxed beakers described by Korver. This modification has also been used by Frey (*Proc. Roy. Soc.*, 1955, *A*, **228**, 510).

The charcoal samples were ashed in porcelain crucibles heated in an electric furnace to not above 700°, to avoid the loss of the more volatile components of the ash which is reported to occur at higher temperatures (Tendolkar and Thakoor, *loc. cit.*). The figures quoted are the means of several determinations.

One of us (A. B.) is indebted to the Kingston-upon-Hull Education Committee for a Maintenance Award.

THE UNIVERSITY, HULL. [*Received, July 12th*, 1955.]

The Stereochemistry of Organic Derivatives of Phosphorus. Part III. The Synthesis and Optical Resolution of a Spirocyclic Phosphonium Salt possessing Molecular Dissymmetry.*

By F. A. Hart and Frederick G. Mann.

[Reprint Order No. 6544.]

Hitherto no spirocyclic phosphonium salt, in which the ring system consists solely of carbon atoms and the phosphorus atom common to both rings, has been synthesised. The considerable difficulties of such synthesis, compared with those of the synthesis of comparable arsonium salts, are briefly indicated. The synthesis of *P-spiro*-bis-1 : 2 : 3 : 4-tetrahydrophosphinolinium iodide, and its resolution into the (+)- and the (−)-iodide, having $[M]_D$ +66° and −65° respectively in chloroform solution, are described. These salts have high optical stability, the rotations of the chloroform solutions at 15° being constant during 4 days.

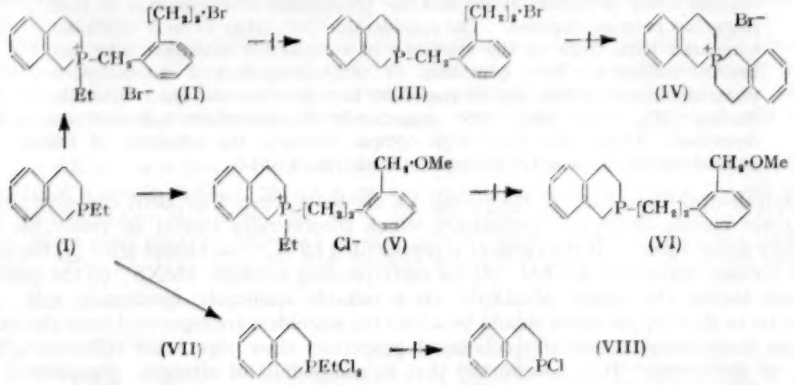
The tetrahedral disposition of the Group Vb elements when 4-covalent can give rise to four main classes of organic derivatives which theoretically should be resolvable into optically active forms. If the element is represented by X, these classes are : (*a*) the oxide of the tertiary derivative, abcXO; (*b*) the corresponding sulphide, abcXS; (*c*) the quaternary salt having the cation $[abcdX]^+$; (*d*) a suitable spirocyclic quaternary salt. The sulphides in class (*b*) (to which should be added the selenides) are separated from the oxides because their chemical and stereochemical properties show significant differences from those of the oxides. It is noteworthy that in compounds of nitrogen, phosphorus, and arsenic this activity in each case has hitherto been experimentally realised in only three of the above classes, although the missing class is different in derivatives of each of the three elements. Thus a tertiary amine oxide, abcNO, was resolved into optically active forms by Meisenheimer (*Ber.*, 1908, **41**, 3966), a quaternary salt, [abcdN]I, by Pope and Peachey (*J.*, 1899, **75**, 1127), and a spirocyclic salt by Mills and Warren (*J.*, 1925, 2507), but tertiary amine sulphides are apparently unknown. A tertiary phosphine oxide was resolved by Meisenheimer *et al.* (*Ber.*, 1911, **44**, 356; *Annalen*, 1926, **449**, 224), a tertiary phosphine sulphide by Davies and Mann (*J.*, 1944, 276), and a quaternary phosphonium salt by Holliman and Mann (*J.*, 1947, 1634), but spirocyclic phosphonium salts, in which the ring system consists solely of carbon atoms and the phosphorus atom which is common to both rings, have not hitherto been synthesised. A tertiary arsine sulphide has been resolved by Mills and Raper (*J.*, 1925, **127**, 2479) and a quaternary and a spirocyclic arsonium salt into optically stable forms by Holliman and Mann (*J.*, 1943, 550; 1945, 45), but attempts to resolve a tertiary arsine oxide, abcAsO, have uniformly failed : this failure, in which the chemistry of arsenic is apparently so different from that of nitrogen and phosphorus, may possibly be due to the conversion $[abcAsOH]X \longrightarrow abcAsO$ through the (usually transient) dihydroxide, $abcAs(OH)_2$, which may itself possess a plane of symmetry (cf. Mann, *J.*, 1945, 71).

We have now synthesised and resolved a spirocyclic phosphonium salt, and the stereochemistry of optically active derivatives of 4-covalent phosphorus has consequently attained a wider basis than that of analogous derivatives of nitrogen or arsenic.

The very ready synthesis of a spirocyclic arsonium salt (Holliman and Mann, *loc. cit.*), dependent upon the smooth thermal decomposition of a quaternary salt, failed signally for analogous phosphonium salts, owing undoubtedly to the different mechanism and more severe conditions of such decompositions. Thus 2-ethyl-1 : 2 : 3 : 4-tetrahydro*iso*phosphinoline (I) (Beeby and Mann, *J.*, 1951, 411) united readily with *o*-2-bromoethylbenzyl bromide, $Br\cdot[CH_2]_2\cdot C_6H_4\cdot CH_2Br$, to give the quaternary salt (II), which when heated under various conditions gave no indication of elimination of ethylene and hydrogen bromide with the formation of the phosphine (III), which would have cyclised spontaneously to the required salt (IV). This result may have been due to the benzyl group's

* Part II, *J.*, 1947, 1634.

being more readily eliminated from (II) than the ethyl group. Consequently the phosphine (I) was next combined with *o*-2-chloroethylbenzyl methyl ether, Cl·$[CH_2]_2$·C_6H_4·CH_2·OMe, to give the salt (V), in the hope that the ethyl group in this would be eliminated before the substituted ethyl group, but again decomposition to the required phosphine (VI) was not achieved. Finally the phosphine (I) was converted into the crystalline dichloride (VII), which, however, unlike its arsenic analogue, on heating dissociated considerably into its original components and did not furnish the monochloro-compound (VIII), from which the phosphine (VI) could undoubtedly have been obtained by the Grignard reaction.

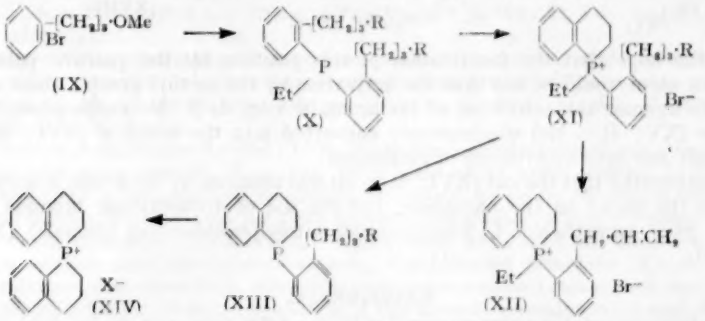


In view of these difficulties, a different synthetic route was adopted, involving thermal decomposition of a quarternary salt having only one alkyl group attached to the phosphorus atom. 3-*o*-Bromophenylpropyl methyl ether (IX) (Beeby and Mann, *loc. cit.*) was converted into the *o*-lithio-derivative, which reacted with ethyldichlorophosphine to give ethyldi-(*o*-3-methoxypropylphenyl)phosphine (X; R = OMe), which was further characterised by conversion into the crystalline orange dibromobis[ethyldi-(*o*-3-methoxypropylphenyl)-phosphine]palladium, $[(C_{22}H_{31}O_2P)_2PdBr_2]$. The phosphine (X; R = OMe) when heated with hydrobromic acid gave the 3-bromopropyl derivative (X; R = Br) which readily cyclised in hot chloroform solution to give the crystalline 1-*o*-3-bromopropylphenyl-1-ethyl-1 : 2 : 3 : 4-tetrahydrophosphinolinium bromide (XI; R = Br), which also gave a crystalline picrate.

The attempted elimination of the ethyl group in the phosphonium bromide (XI; R = Br) by thermal decomposition failed, owing to the ready loss of hydrogen bromide and formation of 1-ethyl-1 : 2 : 3 : 4-tetrahydro-1-*o*-allylphenylphosphinolinium bromide (XII), a process which could apparently be reversed by the action of hot hydrobromic acid. To avoid this type of decomposition, the bromide (XI; R = Br) was converted by sodium methoxide in methanol into the 1-*o*-3-methoxypropylphenyl analogue (XI; R = OMe), which, when heated under nitrogen at 250—320°/1 mm., lost ethylene and hydrogen bromide and gave a viscous distillate of 1 : 2 : 3 : 4-tetrahydro-1-*o*-3-methoxypropylphenylphosphinoline (XIII; R = OMe) and its hydrobromide. A mixture of this crude product and 48% hydrobromic acid, when boiled under reflux, furnished the water-soluble hydrobromide of the 1-*o*-3-bromopropylphenyl analogue (XIII; R = Br): basification precipitated the oily free phosphine, which when extracted with chloroform underwent rapid cyclisation in the boiling extract to (±)-*P-spiro*bis-1 : 2 : 3 : 4-tetrahydrophosphinolinium bromide (XIV; X = Br); this was converted into the less soluble iodide (XIV; X = I). The phosphorus atom in these salts is not asymmetric, but its tetrahedral disposition produces a dissymmetric cation, and the salts should therefore be susceptible to optical resolution. It is noteworthy that simple salts of this cation, such as the iodide and picrate, very readily separate in well-formed crystals, and thus resemble those of the (±)-*As-spiro*bis-1 : 2 : 3 : 4-tetrahydro*iso*arsinolinium cation

(Holliman and Mann, *loc. cit.*) and the *As-spiro*bis*iso*arsindolinium cation (Lyon and Mann, *J.*, 1945, 30).

In preliminary attempts to resolve the cation (XIV), the iodide was converted into the (+)-camphorsulphonate, the (+)-bromocamphorsulphonate, and the (+)-camphornitronate, but these salts after repeated crystallisation gave no evidence of resolution: the (−)-quinate, (−)-*N*-1-phenylethylphthalamate, the (−)-*N*-menthylphthalamate, and the (+)-1-methyl-*n*-hexyl hydrogen phthalate formed intractable oils.



The (−)-menthoxyacetate of the cation (XIV) was also initially obtained as an oil, which however after considerable trouble was obtained crystalline from acetone solution. This material, when repeatedly recrystallised from ethyl acetate, gave the optically pure (−)-phosphonium (−)-menthoxyacetate having ethyl acetate (4 mols.) of crystallisation, m. p. 78—80°, $[M]_D$ −140° in ethanol, both values unchanged by further crystallisation. This salt gave the solvent-free (−)-phosphonium iodide (XIV; X = I), m. p. 246—248°, $[M]_D$ −65° in chloroform.

The mother-liquor from the first of the above recrystallisations, when worked up, furnished a small crop of the (±)-phosphonium (−)-menthoxyacetate, also having ethyl acetate (4 mols.) of crystallisation, m. p. 59—60°, which gave the (±)-phosphonium iodide (XIV; X = I), m. p. 294—295°.

The various mother-liquors, which were now rich in the (+)-phosphonium (−)-menthoxyacetate, were united and evaporated to dryness, and the residue in aqueous solution was converted into the iodide. The latter, when crystallised from ethanol, gave first a crop of the (±)-phosphonium iodide, and then yielded the more soluble (+)-phosphonium iodide (XIV; X = I), which after repeated recrystallisation was obtained optically pure, having m. p. 246—248°, and $[M]_D$ +66° in chloroform.

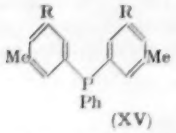
The iodide has high optical stability, and its solution in chloroform at room temperature was unchanged after four days. The calculated values for the rotatory dispersion have

Source of light	Cd	Na	Hg	Cd	Hg
λ (Å)	6438	5893	5461	5086	4358
λ^2 (Å^2) × 10^{-8}	0·414	0·347	0·298	0·259	0·190
α (obs.)	−0·315°	−0·35°	−0·395°	−0·44°	−0·72°
$[M]$	−59·5	−66	−75	−83	−136
α (calc.)	−0·287	−0·35	−0·417	−0·49	−0·72
α (obs.) − α (calc.)	−0·028	0·00	+0·022	+0·05	0·00

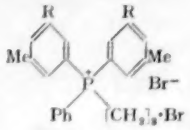
been obtained for a 0·520% solution of the (+)-iodide in chloroform. The calculated rotations are based on the equation $\alpha = k/(\lambda^2 - \lambda_0^2)$, where the rotation constant $k = 0{\cdot}1070$ and $\lambda_0^2 = 0{\cdot}0413$ Å^2. Although the range of wavelengths employed is too short to provide decisive evidence, the differences in the values of α (obs.) −α (calc.) indicate that the dispersion is not simple: this receives strong confirmation from the fact that when λ^2 is plotted against $1/\alpha$ (obs.) a pronounced and smooth curve is obtained, whereas a straight line should be obtained for simple dispersion obeying the above equation.

Some model experiments, conducted to test another synthetic route, are briefly recorded. Phenyldi-*m*-tolylphosphine (XV; R = H) was quaternised with trimethylene dibromide

to give 3-bromopropylphenyldi-*m*-tolylphosphonium bromide (XVI; R = H). The cyclisation by aluminium bromide of the 3-bromopropyl group in this salt on to the *ortho*-position of the tolyl group to give the tetrahydro-5-methylphosphinoline ring was investig-



(XV)



(XVI)

$\{Ph(C_6H_4Me)_2P\cdot[CH_2]_3\cdot P(C_6H_4Me)_2Ph\}Br_2$

(XVII)

ated, in the hope that the inactivation of this position by the positive pole on the phosphorus atom would be less than the activation by the methyl group: these attempts failed. To increase the activation of the aromatic ring, di-(3 : 5-dimethylphenyl)phenylphosphine (XV; R = Me) was similarly converted into the bromide (XVI; R = Me), but this salt also gave no evidence of cyclisation.

It is noteworthy that the salt (XVI; R = H) was obtained by the action of trimethylene dibromide (10 mols.) on the phosphine, but the use of trimethylene bromide chloride (1 mol.) gave trimethylene-1 : 3-bis(phenyldi-*m*-tolylphosphonium bromide) (XVII) in 30% yield.

Experimental

All the following rotations were measured at 15° in a 4-dm. tube, with the Na_D light (λ, 5893Å). All compounds isolated, unless otherwise stated, were colourless.

Reactions of 1-*Ethyl*-1 : 2 : 3 : 4-*tetrahydroisophosphinoline* (I).—The following exemplify briefly the various attempts to synthesise a spirocyclic salt from the phosphine (I).

(1) A solution of the phosphine (I) (0·87 g.) in ether (10 c.c.) was added to one of *o*-2-bromoethylbenzyl bromide (1·36 g., 1 mol.) also in ether (5 c.c.). After 90 min. the crude precipitated oily bromide (II) was separated, dissolved in ethanol, and reprecipitated with ether. The bromide (0·43 g.), which could not be obtained crystalline and gave an oily picrate, effervesced without distillation under nitrogen at 270—350°/0·3 mm., and the brownish-black glassy residue gave no picrate.

(2) A mixture of the phosphine (I) (3·48 g.) and *o*-2-chloroethylbenzyl methyl ether (3·61 g., 1 mol.) was heated under nitrogen at 150—160° for 40 min., forming a hard glass, undoubtedly the chloride (V), which could not be obtained crystalline. This was heated at 360—370°/0·3 mm., undergoing effervescence as a golden oil distilled over. This was shaken with ether and aqueous sodium hydrogen carbonate, and the ethereal extract when distilled gave the phosphine (I), b. p. 70—82°/0·2 mm. (1·15 g.) (b. p. 123—127°/16 mm. on redistillation), and a non-volatile product.

Another portion of the oil was dissolved in a mixture (1 : 1 by vol.) of acetic acid and hydrobromic acid (constant b. p.), which was heated at 130—140° for 2½ hr. whilst hydrogen bromide was passed through it in order to form the bromomethyl analogue of (VI) and then the salt (IV). The acids were therefore removed at reduced pressure, and the residue shaken with aqueous sodium hydrogen carbonate and with chloroform. The aqueous layer gave no precipitate with sodium picrate. The chloroform extract was evaporated: an aqueous solution of the residue gave an oily picrate, but repeated recrystallisation from water gave only an impure picrate, m. p. 39—45° (Found: C, 54·8; H, 3·9%). Lack of material prevented further investigation.

(3) A solution of chlorine (0·60 g., 1 mol.) in carbon tetrachloride (43 c.c.) was added dropwise to a stirred solution of the phosphine (I) (1·5 g.) in the tetrachloride (5 c.c.), immersed in solid carbon dioxide–acetone under nitrogen. A cloudy suspension was rapidly formed and then deposited colourless very hygroscopic crystals (1·99 g., 95%) of the dichloride (VII). They were collected, dried, and heated under nitrogen at 100°/20 mm. for 45 min., until the initial vigorous effervescence had ceased. The residue, when twice distilled at 0·0005 mm. (with some decomp.), gave a cloudy viscous distillate, b. p. 180—185° (Found: Cl, 6·8%), which was still impure and was not identified.

It is noteworthy that 1-ethyl-1 : 2 : 3 : 4-tetrahydrophosphinoline, when added dropwise to carbon tetrachloride at −70°, caused a series of small explosions with the formation of a charred mass. When chlorine diluted with nitrogen was passed over a solution of the phosphine in light petroleum (b. p. 60—80°), it also gave a white crystalline dichloride, which did not furnish the monochloride when heated.

Ethyldi-(o-3-methoxypropylphenyl)phosphine (X; R = OMe).—This experiment was conducted throughout in an atmosphere of nitrogen. *n*-Butyl-lithium in light petroleum (b. p. 40—60°) (1765 c.c.; 0·989N) was slowly added to a stirred solution of 3-*o*-bromophenylpropyl methyl ether (IX) (400 g., 1 mol.) in the petroleum (1·5 l.) at 10°. After the addition of ether (50 c.c.) the mixture was boiled under reflux for 1½ hr., more ether (850 c.c.) being added to dissolve precipitated material. Ethyldichlorophosphine (114 g., 0·5 mol.) in petroleum (500 c.c.) was then added to the cooled, stirred solution, which was again boiled for 1 hr., cooled, and hydrolysed with water. The organic layer, when dried and distilled, gave the *phosphine* (X; R = OMe), b. p. 215—218°/2 mm. (203 g., 65%) (Found: C, 73·9; H, 8·8. $C_{22}H_{31}O_2P$ requires C, 73·7; H, 8·7%).

Shaking with aqueous-ethanolic potassium palladobromide (0·45 mol.), followed by brief boiling, gave *dibromobis[ethyldi-(o-3-methoxypropylphenyl)phosphine]palladium*, pale orange crystals, m. p. 165·5—166·5° (from ethanol) (Found: C, 53·6; H, 6·6. $C_{44}H_{62}O_4Br_2P_2Pd$ requires C, 53·7; H, 6·35%).

1-o-*Bromopropylphenyl*-1-*ethyl*-1 : 2 : 3 : 4-*tetrahydrophosphinolinium Bromide*. (XI; R = Br).—The phosphine (X; R = OMe) (89 g.) was added under nitrogen to 48% hydrobromic acid (1 l.), which was then reduced to *ca.* 200 c.c. by gentle distillation during 1½ hr., care being taken not to overheat the more concentrated solution, which contained the hydrobromide of the phosphine (X; R = Br). This solution was cooled and treated with sodium carbonate solution until effervescence ceased. The liberated phosphine (X; R = Br) was quickly extracted with chloroform, which was then evaporated on a steam-bath, and the residue was heated for a further 15 min. A solution of this crystalline residue in ethanol (40 c.c.) was diluted with ethyl acetate (60 c.c.) and filtered, and more ethyl acetate added until the solution just remained clear: the *bromide monohydrate* (XI; R = Br) slowly separated in needles (63 g.) and further addition of ethyl acetate to the filtrate gave a second crop (31 g., total yield 81%). The salt was purified by a repetition of the above process, and obtained as needles, m. p. 110—112°, unaffected by further treatment (Found: C, 50·4; H, 5·3; Br, 33·95. $C_{20}H_{25}Br_2P,H_2O$ requires C, 50·7; H, 5·7; Br, 33·7%). It gave a *picrate*, yellow needles, m. p. 83—85°, from ethanol (Found: C, 51·95; H, 4·4; N, 7·2. $C_{26}H_{27}O_7N_3BrP$ requires C, 51·7; H, 4·5; N, 6·95%).

Action of Heat on the Bromide (XI; R = Br).—The bromide (0·82 g.) was heated under nitrogen at 0·5 mm. in a flask contained in an oil-bath. Effervescence started at *ca.* 130°, and ceased after the flask had been heated at 150° for 30 min. and then at 200° for 30 min. A solution of the glassy product in a minimum of hot ethanol, when diluted with hot ethyl acetate to incipient turbidity and then set aside, deposited crystals (0·35 g.), m. p. 133—137°, increased to 155—158° by repetition of the crystallisation. This crude bromide (XII), on treatment with aqueous sodium picrate, gave 1-*ethyl*-1 : 2 : 3 : 4-*tetrahydro*-1-o-*allylphenylphosphinolinium picrate* (as XII), yellow crystals, m. p. 130—131° after crystallisation from ethanol and methanol in turn (Found: C, 59·8; H, 5·2; N, 8·15. $C_{26}H_{26}O_7N_3P$ requires C, 59·7; H, 5·0; N, 8·0%).

The picrate was shaken with 25% hydrobromic acid, and the solution, after thorough extraction with ether and treatment with concentrated aqueous potassium iodide, deposited the *iodide* (as XII), m. p. 168—170° after crystallisation from ethanol (Found: C, 56·6; H, 6·1; $C_{20}H_{24}IP$ requires C, 56·9; H, 5·7%).

In earlier attempts to prepare the bromide (XI; R = Br), a solution of the phosphine (X; R = OMe) in a mixture of acetic and 48% hydrobromic acid was boiled under reflux whilst hydrogen bromide was passed through it. Evaporation of the solution under reduced pressure then gave a crude product, a portion of which on recrystallisation gave the bromide (XII). This crude product, when boiled with hydrobromic acid, gave the bromide (XI; R = Br) in good yield. The conversion of the bromide (XII) ⟶ (XI; R = Br) was not attempted, however, with a pure sample of the former.

1-*Ethyl*-1 : 2 : 3 : 4-*tetrahydro*-1-o-3-*methoxypropylphenylphosphinolinium Bromide* (XI; R = OMe).—A solution of the bromide (XI; R = Br) (50 g.) in methanol (60 c.c.) was added at 15° to a solution obtained by the interaction of sodium (4·83 g., 1 atom equiv.) and methanol (90 c.c.), and the mixture set aside for 18 hr. It was then carefully neutralised with hydrobromic acid, and the solvents were removed at 50° under reduced pressure. The residue was extracted with cold ethanol (25 c.c.), which when filtered to remove sodium bromide, and concentrated under reduced pressure, gave the crude crystalline bromide (XI; R = OMe).

This material could not be satisfactorily recrystallised but was pure enough for the next stage. A sample, purified by repeated dissolution in ethanol and reprecipitation with ethyl acetate, gave the crystalline *bromide monohydrate*, m. p. 144—146° (Found: C, 59·9; H, 7·1.

$C_{21}H_{28}OBrP,H_2O$ requires C, 59·3; H, 7·1%). This gave the yellow *picrate*, m. p. 84—96° (from methanol) (Found: C, 58·7; H, 5·5; N, 7·4. $C_{27}H_{30}O_8N_3P$ requires C, 58·6; H, 5·1; N, 7·6%).

(±)-P-spiro*Bis*-1:2:3:4-*tetrahydrophosphinolinium Bromide* (XIV; X = Br).—The bromide (XI; R = OMe) (50 g.) was heated under nitrogen at 2 mm. in a short-necked distilling-flask. Effervescence started when the bath temperature reached *ca.* 250°, and the heating was gradually increased to maintain a slow steady distillation of the product, the process being complete when the temperature reached 320° after *ca.* 1½ hr. The distillate (11·3 g.), the first part of which was a fairly mobile oil and the last part a viscous oil forming a glass when cold, was undoubtedly the phosphine (XIII; R = OMe) increasingly contaminated with its hydrobromide. A mixture of the distillate and 48% hydrobromic acid (100 c.c.) was boiled under reflux for 2 hr., considerably concentrated, cooled, and treated with an excess of aqueous sodium carbonate. The precipitated oily phosphine (XIII; R = Br) was quickly extracted with chloroform, and the latter evaporated on the steam-bath, the residual bromide (XIV; X = Br) finally solidifying. Since crystallisation of this salt proved wasteful, its aqueous solution was treated with an excess of concentrated aqueous potassium iodide, thus precipitating the colourless *iodide* (XIV; X = I) (10·5 g., 24%), m. p. 294—295° after repeated crystallisation from ethanol (Found: C, 55·0; H, 4·8. $C_{18}H_{20}IP$ requires C, 54·8; H, 5·1%). It gave a *picrate*, yellow needles, m. p. 128—129° from ethanol (Found: C, 58·0; H, 4·5; N, 8·8. $C_{24}H_{22}O_7N_3P$ requires C, 58·2; H, 4·5; N, 8·5%).

Resolution of the spiro-*Iodide* (XIV; X = I).—Silver (−)-menthoxyacetate was prepared by Mann and Watson's method (*J.*, 1947, 511). A solution of the iodide (6·43 g.) in hot ethanol (250 c.c.) was added to a suspension of the silver salt (5·24 g., 1 mol.) in boiling water (500 c.c.) containing ethanol (20 c.c.), which was then boiled for 30 min. and filtered. Since, however, a small proportion of the silver menthoxyacetate had decomposed during this process, the filtrate was treated dropwise with a hot saturated aqueous solution of the silver salt until no further turbidity developed, filtered again, concentrated, and ultimately heated at 100° under reduced pressure until only a mobile oil remained.

This oil could not be immediately crystallised. A small sample was stirred vigorously with ether, the latter decanted, and the oil then exposed to the air (for chance inoculation) for long periods: the treatment was repeated with light petroleum, also without success. It was then dissolved in ethyl acetate, and the solution allowed to evaporate spontaneously: this treatment was repeated with acetone and, after many attempts, crystallisation occurred from this solvent, and provided a "seed" for the major quantity.

The latter was dissolved in warm ethyl acetate (20 c.c.), which when cooled and seeded deposited prismatic crystals of the optically impure (−)-phosphonium (−)-menthoxyacetate, m. p. 70—74° (2·9 g.). This crop, when recrystallised from ethyl acetate, gave the salt, m. p. 75—77·5° (1·12 g.); three more recrystallisations gave the solvated (−)-*phosphonium* (−)-*menthoxyacetate* as prisms, m. p. 78—80° (0·67 g.) (Found: C, 66·3; H, 8·5. $C_{30}H_{41}O_3P,4C_4H_8O_2$ requires C, 66·3; H, 8·8%). These prisms, which were well-formed crystals, when finely crushed gave a faint odour of ethyl acetate. A 0·812% solution in ethanol had α −0·545°, $[M]$ −140°. One more recrystallisation gave the salt of unchanged m. p., and a 0·63% ethanolic solution then had α −0·425°, $[M]$ −140°. Meanwhile, the mother-liquor which had deposited the above crop, m. p. 75—77·5°, on spontaneous partial evaporation deposited a second crop, which on recrystallisation furnished more (−)-phosphonium salt (0·94 g.), identical with the former final product.

This salt in aqueous solution, when treated with aqueous potassium iodide, deposited the (−)-*phosphonium iodide* (XIV; X = I), needles, m. p. 246—248° after crystallisation from ethanol (Found: C, 55·0; H, 5·3. $C_{18}H_{20}IP$ requires C, 54·8; H, 5·1%); a 0·668% solution in chloroform had α −0·44°, $[M]$ −65°.

The original mother-liquor, which had deposited the salt of m. p. 70—74°, on spontaneous evaporation furnished a viscous semisolid residue; this was drained and the sticky solid (2·35 g.), when recrystallised from ethyl acetate (5 c.c.), gave a mixture (m. p. 55·5—57°; 0·75 g.) mainly of needles containing the higher-melting prisms. A solution of this mixture in ethyl acetate (5 c.c.), when cooled and seeded with the above (−)-phosphonium (−)-menthoxyacetate, deposited *ca.* 0·1 g. of the latter. This was collected, and the filtrate, when reheated and allowed to cool, deposited uncontaminated needles of the solvated (±)-*phosphonium* (−)-*menthoxyacetate* (0·23 g.), m. p. 58—60°, unchanged by further crystallisation (Found: C, 66·4; H, 8·8. $C_{30}H_{41}O_3P,4C_4H_8O_2$ requires C, 66·3; H, 8·8%). This gave the (±)-phosphonium iodide, m. p. 294—295°, alone and when mixed with the original salt.

The ethyl acetate mother-liquors from the above work were united [omitting only those used for the final recrystallisations of the (−)-phosphonium salt] and evaporated to dryness under reduced pressure. The residue in aqueous solution, when treated with aqueous potassium iodide, deposited the iodide (2·34 g.), m. p. 240—280°. A solution of this salt in boiling ethanol (75 c.c.) was allowed to cool spontaneously without disturbance: after 4 hr., a crop of the (±)-phosphonium iodide (0·92 g.), m. p. 287—289°, was rapidly collected, the solution being supersaturated with respect to the (+)-phosphonium iodide. The filtrate, when concentrated to 50 c.c. and rapidly cooled, gave the (+)-phosphonium iodide (0·64 g.), m. p. 245—246·5°, which after seven recrystallisations from ethanol gave the optically pure *iodide*, m. p. 246—248° (Found: C, 55·0; H, 4·8%); a 0·520% solution in chloroform had α +0·35°, $[M]$ +66° (for rotations at other wave-lengths, see p. 4109).

The following salts of the spirocyclic cation were also prepared: The (±)-*phosphonium* (+)-*camphorsulphonate* was obtained by mixing hot aqueous solutions of equimolar quantities of the phosphonium iodide and of the silver sulphonate, and evaporating the filtrate to dryness under reduced pressure. The residue, recrystallised six times from ethyl methyl ketone, gave the sulphonate (XIV; X = $C_{10}H_{15}O_4S$), m. p. 170·5—171·5° (Found: C, 67·2; H, 7·2. $C_{28}H_{35}O_4SP$ requires C, 67·4; H, 7·1%): it gave an inactive iodide. The (+)-*bromocamphorsulphonate*, similarly prepared, gave an oil which solidified when rubbed with acetone, and when then recrystallised five times from ethyl methyl ketone had m. p. 184·5—185·5°, $[M]$ +289° (Found: C, 58·4; H, 6·2. $C_{28}H_{34}O_4BrSP$ requires C, 58·25; H, 5·9%): it also gave an inactive iodide. The (+)-*camphornitronate*, similarly prepared and recrystallised eight times from the ketone, had m. p. 150—152° (Found: C, 72·6; H, 7·6; N, 3·2. $C_{28}H_{34}O_3NP$ requires C, 72·6; H, 7·4; N, 3·0%): it gave an inactive picrate.

Phenyldi-m-tolylphosphine (XV; R = H).—A solution of phenyldichlorophosphine (20·5 g.) in benzene (100 c.c.) was slowly added under nitrogen to a stirred Grignard reagent prepared from *m*-bromotoluene (49·3 g., 2·5 mols.) in ether (150 c.c.) and magnesium (7·0 g.). The mixture was boiled under reflux for 1½ hr., cooled, and hydrolysed with aqueous ammonium chloride. The organic layer, when separated, dried, and distilled, gave the *phosphine*, b. p. 210—220°/0·5 mm. (26 g., 75%), which readily solidified and gave crystals, m. p. 53—53·5°, from methanol (Found: C, 82·8; H, 6·7. $C_{20}H_{19}P$ requires C, 82·7; H, 6·6%). The phosphine was characterised by treatment of a portion in chloroform with bromine (1 mol.), and hydrolysis of the dibromide by shaking its solution with dilute aqueous ammonia. The chloroform layer on evaporation gave the colourless *phosphine oxide*, m. p. 108·5—109° from light petroleum (b. p. 60—80°) (Found: C, 78·4; H, 6·5. $C_{20}H_{19}OP$ requires C, 78·4; H, 6·25%).

Di-(3 : 5-dimethylphenyl)phenylphosphine (XV; R = Me) was similarly prepared from 1-bromo-3 : 5-dimethylbenzene; the crude product, b. p. 150—195°/1 mm., solidified, and when thrice recrystallised from methanol gave the phosphine, m. p. 98° (Found: C, 83·1; H, 7·2. $C_{22}H_{23}P$ requires C, 83·0; H, 7·3%).

3-Bromopropylphenyldi-m-tolylphosphonium Bromide (XVI; R = H).—A mixture of the phosphine (XV; R = H) (5 g.) and trimethylene dibromide (34·8 g., 10 mols.) was heated under nitrogen at 100° for 3 hr. Addition of ether to the cold product yielded the *salt* (8·3 g., 98%) which on repeated recrystallisation from ethanol–ethyl acetate (1 : 10 by vol.) had m. p. 190·5—191·5° (Found: C, 56·4; H, 4·95. $C_{23}H_{25}Br_2P$ requires C, 56·1; H, 5·1%).

Trimethylene-1 : 3-bis(phenyl-m-tolylphosphonium Bromide) (XVII).—A mixture of the phosphine (XV; R = H) (3 g.) and trimethylene chlorobromide (1·63 g., 1 mol.) was heated at 150° for 40 min. The solid product (3·72 g.; m. p. 173—250°) was triturated with ether, and when recrystallised once from ethanol and twice from water gave the *bromide* (0·96 g., 30%), m. p. 314—315° (Found: C, 65·9; H, 5·8. $C_{42}H_{44}Br_2P_2$ requires C, 66·0; H, 5·7%).

3-Bromopropyldi-(3 : 5-dimethylphenyl)phenylphosphonium Bromide (XVI; R = Me).—This *bromide*, prepared as (XVI; R = H), formed crystals, m. p. 203—205°, when slowly precipitated from ethanolic solution by the addition of ethyl acetate (Found: C, 57·4; H, 5·3; Br, 30·6. $C_{25}H_{29}Br_2P$ requires C, 57·7; H, 5·6; Br, 30·7%).

Di-α-naphthylphenylphosphine.—Prepared by the action of α-naphthylmagnesium bromide on phenyldichlorophosphine, this *phosphine* formed crystals, m. p. 207·5—208·5°, from ethyl methyl ketone (Found: C, 86·15; H, 5·4. $C_{26}H_{19}P$ requires C, 86·2; H, 5·3%). In view of the failure to cyclise the bromides (XVI; R = H and Me), the interaction of this phosphine and trimethylene dibromide was not investigated.

The following compounds were prepared as reagents for attempted resolutions. (−)-*N-Menthylphthalamic Acid.*—(−)-Menthylamine (8·1 g.) in ether (150 c.c.) was added to a boiling solution of phthalic anhydride (7·75 g., 1 mol.) in ether (300 c.c.), which was heated under reflux for

1 hr., and then concentrated to *ca.* 50 c.c. Careful addition of light petroleum (b. p. 40—60°) (400 c.c.) precipitated the white *acid* (15·1 g., 95%), m. p. 154·5—155·5° after recrystallisation from di-*n*-butyl ether (Found: C, 71·6; H, 8·1; N, 4·3. $C_{16}H_{25}O_3N$ requires C, 71·3; H, 8·3; N, 4·6%). The addition of silver nitrate (1 mol.) to the sodium salt, each in aqueous solution, precipitated the *silver salt monohydrate*, m. p. 222° (decomp.) (Found: Ag, 25·2. $C_{16}H_{24}O_3NAg,H_2O$ requires Ag, 25·2%).

(+)-1-Methyl-*n*-hexyl hydrogen phthalate similarly gave a *silver salt monohydrate*, m. p. 130—133° (preliminary softening) (Found: Ag, 27·9. $C_{15}H_{19}O_4Ag,H_2O$ requires Ag, 27·8%).

We are greatly indebted to Dr. M. H. Beeby for the preparation of the phosphine (XV; R = H), to Dr. J. Kenyon, F.R.S., for the gift of (+)-1-methyl-*n*-hexyl hydrogen phthalate, and the Department of Scientific and Industrial Research for a grant (to F. A. H.).

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Solvent Participation in Nucleophilic Displacement Reactions. Part I. General Considerations.

By R. F. Hudson and B. Saville.

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Attention is drawn to the inadequacy of the Born–Kirkwood theory of solvation as applied to reactions with polar transition states. The close similarity between the solvation of inorganic ions and organic transition states is discussed in terms of specific solvation. This leads to the conclusion that the solvation energy of the anion is generally much greater than that of the cation in agreement with the strong electrophilic catalysis observed in ionisation reactions.

The significance of activation entropy in liquid mixtures is discussed in terms of specific solvation, and under some conditions the entropy is shown to be related to the composition of the mixture. The influence of covalent-bond formation on the extent of solvent participation is briefly discussed.

Although the effect of structural changes on the rate of reactions leading to pseudo-ionic (or ionic) transition states has been studied extensively, the influence of changes of solvent has received comparatively little attention owing largely to the unsatisfactory state of theoretical knowledge of liquid structure. This is particularly serious as it is becoming increasingly evident that mechanism and environment are closely correlated. However, the prevalent theories of organic substitution reactions are largely empirical, and hence by analogy one might expect that semi-empirical treatments of solvent effects would be the most rewarding at present.

The experimental work described in the following papers was undertaken with this in mind, and the following discussion gives a brief critical survey of the present position.

The Born–Kirkwood Treatment.—The effect of changing the solvent on the rate of reaction involving a polar transition state has usually been investigated by considering the corresponding changes in the free energy of activation (see Glasstone, Laidler, and Eyring, "Theory of Rate Processes," New York, 1941, Chapter 8). If this is referred to a standard reference state, *e.g.*, the vapour phase, the general rate equation shows that

$$\log k = \log k_0 - \Delta F^*/RT$$

where ΔF^* is the free-energy change on transferring the reacting system from vacuum to the medium under consideration. If long-range electrostatic forces only are considered, ΔF^* is given by the appropriate Born charging energy (Born, *Z. Physik*, 1920, **1**, 45), and hence it follows that

$$\log k = \log k^\circ - f(D,r_a,r_b,r^*)$$

where D is the dielectric constant of the medium, and r_a, r_b, and r^* are the effective radii of reactants and transition state respectively.

This type of equation does not hold in media of low polarity owing to the failure of the necessary condition $\mu^2/DkTr^3 \ll 1$ (Bell, *Trans. Faraday Soc.*, 1935, **31**, 1557), and has therefore in general been applied to kinetic data in highly polar media (see Glasstone, Laidler, and Eyring, *op. cit.*).

Any equation of this type requires the rate to be an increasing function of dielectric constant for reactions between neutral molecules, the transition-state structure being assumed to remain constant. Examination of the available data, however, shows a complete lack of correlation between these two quantities (*e.g.*, see Moelwyn-Hughes, " Kinetics of Reaction in Solution," Oxford, 1947; Le Fèvre and Northcott, *J.*, 1949, 944; Brown and Hudson, *J.*, 1953, **3352**), and in many cases increases in dielectric constant lead to considerable decreases in reaction velocity, irrespective of the nature of the reaction (*e.g.*, whether it is an S_N1 or an S_N2 process). For example, Norris and Haines (*J. Amer. Chem. Soc.*, 1953, **75**, 1425) found that the rate of alcoholysis in 1M-alcohol solution is approximately constant in a large number of solvents (particularly if non-polar solvents are excluded). Fairclough and Hinshelwood have given several examples of unequal rates in isodielectric media (*J.*, 1937, 538).

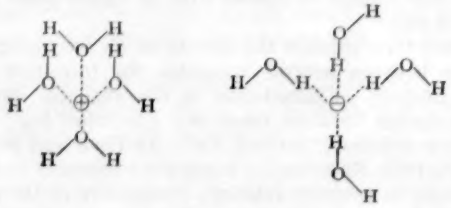
The cases where k is related quantitatively to D usually involve regular changes in a particular solvent mixture such that the concentration of the more polar constituent (and hence D) is varied. On the other hand, examples are known where such a regular change increases k but decreases D (Gelles, Hughes, and Ingold, *J.*, 1954, 2918). The rate is frequently determined fairly closely by the concentration of the more polar constituent; thus, Hudson and Brown (*J.*, 1953, 883) found the rate of hydrolysis of several acid chlorides to be almost equal in 95% aqueous acetone (v/v) and 95% aqueous dioxan in spite of the considerable difference in dielectric constant and similar conclusions may be drawn from the recent results of Cropper, Olsen, and Spieth (*J. Amer. Chem. Soc.*, 1954, **76**, 6248) for an ionisation reaction. However, the rate of reaction of *p*-nitrobenzoyl chloride in 5% aqueous formic acid (which has a very high value of *D and* solvating power—see p. 4116) is considerably less than in these solvents (Crunden and Hudson, unpublished work). This is attributed to the increased bond energy between water and formic acid, compared with the bond energy between hydroxyl groups and ketones, ethers, alcohols, etc. (see Davies, *Ann. Reports*, 1946, **43**, 15).

These examples are sufficient to show that the rates of reactions of this kind are determined primarily by specific solute–solvent interactions, and consequently the influence of long-range electrostatic forces is only a secondary factor. This has long been recognised in equilibrium processes, by attempted calculations of internal dielectric constants (*e.g.*, Debye, *Z. phys. Chem.*, 1927, **130**, 56; Webb, *J. Amer. Chem. Soc.*, 1926, **48**, 2589; Kirkwood, *J. Chem. Phys.*, 1939, **7**, 911; Oster and Kirkwood, *ibid.*, 1943, **11**, 175; Oster, *J. Amer. Chem. Soc.*, 1946, **68**, 2036), but in general the resulting expressions are too complex to be applied to kinetic data.

The Bernal–Fowler Method.—The effect of solvent on the rate of organic reactions raises essentially the same problems as in the solvation of inorganic ions, which has been treated fairly satisfactorily by Bernal and Fowler (*J. Chem. Phys.*, 1933, **1**, 515). This treatment leads to the important conclusion that the inner shell of solvent molecules determines most of the energy and entropy changes. Thus the Born charging energy contributes only about 30% of the heat and about 10% of the entropy of solvation of simple ions (Eley and Evans, *Trans. Faraday Soc.*, 1938, **34**, 1093). As shown later, the latter value is of the greatest significance in solvolytic reactions. It is convenient therefore to distinguish between the two types of interaction, termed interaction and environmental energy by Banks (*ibid.*, 1937, **33**, 215). This " freezing " of water molecules around the central ion has been discussed in considerable detail by Frank (*J. Chem. Phys.*, 1945, **13**, 793).

Complete theoretical estimations of the thermodynamic functions have been made only for simple salts in water, usually by the Bernal–Fowler method (*loc. cit.*), but it is of interest to consider solvation in aqueous mixtures in this way. According to this treatment, the water and ice structures are taken to be given by a tetrahedral arrangement of molecules around each central molecule. The heat of solvation is calculated by assuming this assembly to be removed to the gas phase, the central molecule replaced by an ion and

returned to the liquid phase, and the four remaining molecules reorientating to the position of minimum energy:



Finally, the hydrated ion is returned to the liquid phase, and the enthalpy of Born charging taken into account. In calculating the interaction energy between the ion and the nearest solvent molecules the coulombic energy between the ion and each formal charge on the dipole was considered, as the usual ion–dipole relation cannot hold over such short distances. This leads to some uncertainty in the calculations, but the absolute magnitude of such charges is not important in the present discussion.

Entropies of solvation can be calculated by using the Sackur–Tetrode equation giving the standard gas entropy, then by assuming that all translational entropy is momentarily lost, the loss in entropy associated with the formation of the inner co-ordination shell is obtained. The resulting hydrated ion is finally allowed to move through the free volume of the liquid, thus creating entropy.

Partition functions for radial motion of n water molecules vibrating (1) in the field of a water molecule and (2) in the field of an ion are assumed to take the form $\phi = h\nu/kT$ per vibrator, where ν is the vibration frequency calculated from a likely value of the force field f of the quasi-harmonic vibration $\nu = \frac{1}{2\pi} \cdot \left(\frac{f}{\mu}\right)^{\frac{1}{2}}$ where μ is the reduced mass. Similar partition functions may be calculated to allow for lateral movement of water molecules on the surface of the ion, and for restricted rotation (libration) of the dipoles in symmetrical force fields associated with water on the one hand and with the ion on the other. The entropy contributed by the more distant water molecules is given by the standard thermodynamic relation $\Delta S = (\partial \Delta F/\partial T)_p$, where ΔF is the free energy of Born charging (see Pearson, *J. Chem. Phys.*, 1952, **20**, 1478).

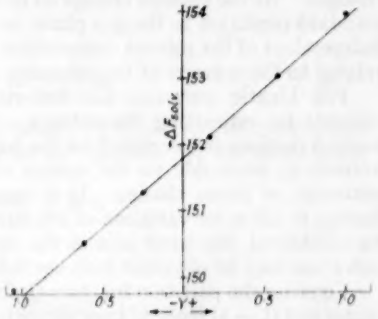
This type of treatment may in principle be extended to ionic reactions, as there is considerable evidence to show that solvent influences are similar to the solvation of inorganic ions. Thus the free energy of ionisation of alkyl halides in the gas phase is of the same order of magnitude as the compensating free energy of solution of inorganic salts in aqueous media (Evans, *Trans. Faraday Soc.*, 1946, **42**, 719). By taking into account the radius of the cation, which is normally inversely proportional to the solvation energy (Latimer, Pitzer, and Slansky, *J. Chem. Phys.*, 1939, **7**, 108), rates of solvolysis can be estimated approximately by assuming the transition state of the ionisation reaction to be in the form of an ion-pair (Franklin, *Trans. Faraday Soc.*, 1952, **48**, 443). Moreover, the change in rate on changing from water to methanol is given closely by the corresponding change in free energy of solvation of inorganic ions of similar dimensions (Brown and Hudson, *loc. cit.*).

This close similarity can be demonstrated by applying Grunwald and Winstein's empirical equation (*J. Amer. Chem. Soc.*, 1948, **70**, 846) relating the rate of S_N1 solvolysis to solvating power, Y, as evaluated from experimental data on a "calibration" reaction, to the solvation of inorganic ions. This equation takes the form $\log k_1 = \log k^\circ + mY$, where m is a specific constant for each reaction, unity in the case of the "calibration" reaction. Comparison with the general rate equation shows that

$$-(\Delta F_1 - \Delta F_2) = 2{\cdot}3RTm\,(Y_1 - Y_2)$$

The changes in the parameters of Grunwald and Winstein's equation may therefore be identified with the differences in free energy of ionic solvation in different media.

This linear relation holds for the solvation energy of salts in alcohol–water mixtures (Latimer and Slansky, *ibid.*, 1940, **62**, 2020), Y values determined experimentally from rate measurements (see Fig.) being used. The value of m for potassium chloride is 1·505 compared with 1·00 for *tert.*-butyl chloride. This difference may be attributed to the difference in size of the K^+ and Bu^{t+} ions, or to internal assistance to ionisation in the case of the organic halide. This comparison indicates that the energy of ionisation of a covalent molecule is given by the same type of solvation forces as are involved in the solvation of inorganic ions. Further support for this view may be obtained by comparison of changes in energies of activation of ionisation reactions as the medium changes with the corresponding changes in the heats of solvation of inorganic ions (Askew, Bullock, Smith, Tinkler, Gatty, and Wolfenden, *J.*, 1934, 1368). For simple salts $-\Delta H$ in alcohols is



" Solvating power " (Y) plotted against free energy of ionic solvation ($-\Delta F_{solv.}$) for K^+Cl^- in methanol–water at 25°.

slightly greater than in water (see Table), which is probably due to an increase in solvation energy of the cation * as a result of the electron release R ⟶ OH. As the size of the cation increases, however, this order is reversed (see Table). The solvation energy of the

Change in heat of solvation ($-\Delta H$) on change of solvent.

	H_2O ⟶ MeOH	H_2O ⟶ EtOH
LiCl	+3·8	+4·3
NaCl	+3·5	—
KCl	+2·9	—
NMe_4Cl	−2·06	−2·40
NEt_4Cl	−3·02	−4·75
NEt_4Br	−2·78	−3·66
Bu^tCl *	−2·10	−3·10
Bu^tBr *	—	−2·20

* From activation energy on the assumption that the change is due to the change in solvation energy only.

halide ion thus becomes more important than that of the cation, as solvation energy is inversely proportional to size (Latimer *et al.*, *loc. cit.*). Similarly, an increase in the size of the anion from chloride to bromide increases the relative importance of the cation solvation energy, with a corresponding increase in the solvation energy in alcohol relative to that in water. In further agreement with this explanation it is observed that the effect is more pronounced in ethanol than in methanol both for small and for large cations. The activation energy for the solvolysis of the *tert.*-butyl halides changes in a similar way to the heat of solvation of tetramethylammonium halides, in agreement with the general explanation. It is well known that carbonium ions are much more readily formed in acidic solvents, *e.g.*, carboxylic acids and phenol, than in basic solvents, *e.g.*, ethers and tertiary amines (see Evans, Price, and Thomas, *Trans. Faraday Soc.*, 1955, **51**, 481) which supports the conclusion that ionisation is produced largely by electrophilic action.

Bernal–Fowler Theory applied to Mixtures.—In many liquid mixtures, the activation energy is found to be relatively insensitive to changes in composition (see, *e.g.*, data compiled

* The direction of this change is in agreement with the predictions of Born's treatment.

by Grunwald and Winstein, *loc. cit.*). This may be attributed to the specific nature of the solvation (by the more polar constituent), subject to the following conditions: (*a*) No change in transition-state structure (Brown and Hudson, *loc. cit.*). (*b*) The energy of association between solvent molecules A and B is approximately equal to that between 2A molecules (where A is the more polar). This condition may be satisfied in solvolysis where hydrogen-bonding liquids are employed, as hydrogen-bond energies in alcohols, ketones, ethers, and water are probably very similar (see Davies, *loc. cit.*).

In media of this kind, therefore, the rate is determined largely by entropy changes (a fact which is not always recognised). The solvent effect may therefore be calculated in principle by assuming that the ions are solvated specifically by the co-ordination * of n (hydroxylic) molecules, and estimating the entropy differences as the solvent composition changes. As the entropy change on co-ordinating n water (or alcohol) molecules from some standard condition in the gas phase on to the transition state may be taken to be almost independent of the solvent composition, the change in entropy on change of solvent will be related to the entropy of the solvating component in the mixture.

For kinetic purposes the free-volume theory of liquids seems to be the most suitable for estimating the entropy. The entropy of a molecule undergoing classically excited motions is calculated on the basis that its equivalent translational movement in a volume v_x accessible to the centre of gravity of the molecule completely determines entropies of phase change. It is appreciated that, in a refined treatment, fluctuation factors to allow for variation of cell size with temperature, communal entropy, etc., should be considered, but some idea of the significance of activation entropy in terms of specific solvation may be obtained from the following simplified approach.

Consider the partition function Q_x for a water molecule in a solvent containing x mols. of water and $(1 - x)$ mols. of inert solvent. Q_x may be factorised into Q_{ix} and $v_f(2\pi m_x \boldsymbol{k}T/\boldsymbol{h}^2)^{3/2}$ where Q_{ix} is the partition function of x due to molecular vibrations, librations, etc., and is approximately independent of environment of the water, and the other factor is the partition function due to translational motion in three degrees of freedom within the free-volume box v_f. Since

$$Q_x = Q_{ix} v_f (2\pi m_x \boldsymbol{k}T/\boldsymbol{h}^2)^{3/2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and

$$S = \partial(\boldsymbol{R}T \ln Q)/\partial T \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$S = \boldsymbol{R}[\ln Q_{ix}(2\pi m_x \boldsymbol{k}T/\boldsymbol{h}^2)^{3/2} + T\partial(\ln Q_{ix} \cdot 2\pi m_x \boldsymbol{k}T/\boldsymbol{h}^2)^{3/2}/\partial T + \ln v_f + T\partial \ln v_f/\partial T] \quad (3)$$

Eqn. (3) can be simplified at constant temperature to

$$S = \boldsymbol{R}(a + \ln \gamma\, v_f) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3a)$$

where γ is used to absorb into v_f the effect of the last term in (3). If v_{fx} is the free volume of water and $v_{f(1-x)}$ that of the other component of the binary liquid mixture, then the total free volume of the solution can be represented (Eyring, Hirschfelder, and Stevenson, *J. Chem. Phys.*, **1937**, **5**, 896) by

$$v_f = v_{fx}^{x}\, v_{f(1-x)}^{(1-x)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The free volume per water molecule is therefore,

$$v_f/x_v = \{v_{fx}^{x} v_{f(1-x)}^{(1-x)}\}/x_v \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

From (3*a*) the entropy of water in the binary solvent is given by

$$S = \boldsymbol{R}[a + \ln \gamma + x \ln v_{fx} + (1 - x) \ln v_{f(1-x)} - \ln x_v] \quad . \quad . \quad . \quad (6)$$

It follows from this equation that the volume composition is related stoicheiometrically to the entropy, *i.e.*,

$$\frac{\partial(\Delta S)}{\partial x_v} = \frac{\boldsymbol{R} \ln v_{fx}}{v_{f(1-x)}} \cdot \frac{\partial x}{\partial x_v} - \frac{\boldsymbol{R}}{x_v}$$

* This term is used to denote the operation of short-range electrostatic forces, and not necessarily the formation of dative bonds.

where x_w is the volume fraction of water. If the free volumes of water and the other component are not too different, (6) reduces to the simple relation

$$S = \boldsymbol{R}(\text{const.} - \ln x_w) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

If we assume that n water molecules co-ordinate around an ion or ion-pair, the entropy change on solvating an ion from a liquid having a volume fraction of x_w is

$$\begin{aligned} \Delta S &= n(-\Delta S_1 + S) \\ &= n(-\Delta S_1 + \text{const.} - \boldsymbol{R} \ln x_w) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8) \end{aligned}$$

where ΔS_1 is the entropy change of solvating an ion with one water molecule from standard conditions in the gas phase.

According to the absolute rate equation,

$$k_0 = (\boldsymbol{k}T/\boldsymbol{h}) \exp(\Delta S^*/\boldsymbol{R}) \exp(-\Delta H^*/\boldsymbol{R}T) \quad . \quad . \quad . \quad . \quad (9)$$

where ΔH^* and ΔS^* are the heat and entropy of activation. The entropy of the gaseous transition state will be reduced by an amount given in equation (8) on undergoing solvation; *i.e.*,

$$\begin{aligned} \Delta S^* &= \Delta S_0^* - n(-\Delta S_1 + \text{const.} - \boldsymbol{R} \ln x_w) \\ &= \text{constant} + n\boldsymbol{R} \ln x_w \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10) \end{aligned}$$

thus from equation (9),

$$2{\cdot}3 \log_{10} k_0 = 2{\cdot}3 \log_{10} [(\boldsymbol{k}T/\boldsymbol{h}) \exp(-\Delta H/\boldsymbol{R}T)] + \Delta S^*/\boldsymbol{R} \quad . \quad . \quad (11)$$

Substituting (10) into (11), we have

$$\log_{10} k_0 = 2{\cdot}3 \log_{10} \text{const.} + n \log_{10} x_w \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

This treatment shows that the entropy of solvation, and hence the reaction rate, are related simply to the volume composition of the liquid mixture under certain conditions. Such a relation will hold most satisfactorily when the two components of the mixture differ considerably in solvating power, but also requires random distribution of the two kinds of solvent molecule. The first requirement is readily satisfied in most liquid mixtures, but the distribution of the molecules in a solvent is a complex function of interaction energies, molecular size, and free volume. As already pointed out, however, strong hydrogen-bonding between the two components of a mixture will tend to distribute the molecules at random.

A relation of this kind has been found to hold over a fairly wide concentration range in acetone–water mixtures for several ionisation reactions (Brown and Hudson, *loc. cit.*). Olsen and Cropper (*loc. cit.*) have adduced a relation between the velocity of ionisation reactions and mole-fraction of water over a wide range of solvent composition. In these cases n is roughly constant ($n = 4{\cdot}0$—$4{\cdot}7$), which again may be explained by the greater solvation energy of the halide ion (see p. 4117) than of that of the cation.

It follows from the above discussion that reactions involving ionisation will in general occur in the electrostatic field of a specific number of molecules (which may of course vary with the solvent composition), and hence the order of reaction with respect to molecules of a particular kind will be related closely to the kinetic order of the solvation process, *i.e.*, to the number of molecules of a certain species participating in the solvation of the transition state. This will be investigated further by analysing the experimental data recorded in Parts II and III (following papers).

Influence of Covalent-bond Formation.—So far the discussion has been concentrated on reactions which proceed by a rate-determining ionisation process (S_N1 type). It is of interest to apply the above principles to reactions in which the rate is determined partly by bond formation between the two reactants (S_N2 type). Again, solvation is necessary to

reduce the activation energy to permissible values, but the effect of solvent changes on rate is generally smaller than in the case of an ionisation reaction, at least under solvolytic conditions (Dostrovsky, Hughes, and Ingold, *J.*, 1946, 167). This is a consequence of the different driving forces in the two cases, as may be shown by the following simple argument. In the case of an S_N1 ionisation, a considerable increase in C–X polarity is essential in order to reach the potential-energy maximum, as the process is fundamentally a single-bond stretching with simultaneous charge transfer. Ingold and Hughes have assumed a transition state structure corresponding to " half ionisation," and a bond extension of *ca.* 0·1 Å. Approximate calculations of the activation energy, however, indicate that the transition state resembles the final state closely (Evans, *loc. cit.*; Franklin, *loc. cit.*), and it seems likely that the transition state resembles an " intimate ion-pair " (Winstein *et al.*, *Chem. and Ind.*, 1954, **664**). The process may then be represented as follows :

$$R_3C\cdot\overset{\delta+}{}\ \overset{\delta-}{X} \rightleftharpoons R_3C\cdot\overset{\Delta+}{}\ \overset{\Delta-}{X} \rightleftharpoons R_3C^+X^-$$

In the case of an S_N2 process, however, an increase in charge is not *essential* in the formation of the transition state, since a transfer of electrons from substituting atom Y to the carbon atom causes a weakening of the C–X bond :

$$Y: + R_3C\ \overset{\delta+}{}\ \overset{\delta-}{X} \rightleftharpoons Y\cdots\overset{R}{\underset{R}{\overset{|}{C}}}\cdots X \longrightarrow YCR_3^+ + X^-$$

If the C–X bond is weak, the transition-state structure may resemble that given in the above equation, but in general, further charge separation occurs. In this case, the additional energy required for the further stretching of the C–X bond is given largely by the increasing Y–C bond energy, and consequently the contribution of solvation energy will be considerably less than in a direct ionisation. This argument depends on a close correlation between the extent of bond stretching and electron transfer to X, and is similar to that of Marshall and Winstein (*J. Amer. Chem. Soc.*, 1952, **74**, 1120) who describe the transition state as a mixture of the canonical structures :

$$\underset{\text{(I)}}{Y:\ RX} \qquad \underset{\text{(II)}}{\overset{+}{Y}:R\ \bar{X}} \qquad \underset{\text{(III)}}{Y:\ \overset{+}{R}\ \bar{X}}$$

The gradual change from an S_N1 to an S_N2 process may be regarded as a gradual decrease in the contribution of structure (III). Quite recently, Hammond (*ibid.*, 1955, **77**, **334**) has discussed in some detail the generalisation that the transition state of an ionisation reaction resembles that of the products, whereas that of an S_N2 process will tend to resemble the reactants more closely.

If the Born–Kirkwood treatment is applied to reactions with these two kinds of transition states, it readily follows that the solvent effect is greater for the S_N1 process. Suppose the charges εe are localised at particular positive and negative poles in the system, and reaction involves the same charge increases in the two cases. Then the magnitude of the solvent effect for a given change in D will be given by $\sum(\varepsilon^2e^2/r)$. The radius of the transition state, r, is greater for the S_N2 than for the S_N1 process (if the charge is supposed to be localised along the C–X bond in this case), and moreover the sum term includes an additional term for the nucleophilic reagent in the case of the S_N2 reaction. Consequently $\sum(\varepsilon^2e^2/r)$ and hence the solvent effect are greater for the S_N1 process. This interpretation is analogous to the view of Hughes and Ingold (*J.*, 1935, 252; Cooper, Dhar, Hughes, Ingold, Macnulty, and Woolf, *J.*, 1948, 2043) that the charge is more dispersed in an S_N2 transition state, thus leading to reduced solvent interaction.

As already shown, however, the solvation energy calculated by the Born–Kirkwood treatment is only a fraction of the total interaction energy. The short-range interactions of the nearest solvent molecules with the two poles of the dipole provide the greater part of

the interaction energy whether dipoles (see Le Fèvre and Northcott, *loc. cit.*) or ions are under consideration. Accordingly, the greater solvent effect usually observed in S_N1 reactions is more probably due to the greater formal charges in the transition state, and in particular, for the reasons already discussed, to the magnitude of the negative charge on the halogen atom. This view, as already mentioned, requires the assumption that the charge remains in the C–X bond in an ionisation reaction. Although the position of the negative charge in the reactant and transition state is known, the position of the positive charge in either system is uncertain. Thus the stability of the carbonium ion is attributed to conjugation involving the participation of a large number of canonical structures (Baughan, Evans, and Polanyi, *Trans. Faraday Soc.*, 1941, **37**, 385; Butler and Polanyi, *ibid.*, 1943, **39**, 19). This necessarily requires considerable delocalisation of the charge in the positive radical. On the other hand, the positive charge in the corresponding S_N2 process is likely to be shared between atoms Y and C, and hence may be more localised:

$$\overbrace{Y\cdots C}^{\delta+}\cdots\overset{\delta-}{X}$$

We conclude, therefore, that the greater solvent effect in an S_N1 process is due primarily to the greater negative charge on the leaving group, thus resulting in the specific interaction of a greater number of electrophilic solvent molecules in the transition state. This will be reflected in the kinetic order of the reaction under suitable conditions, and this relation is investigated in some detail in the following papers.

QUEEN MARY COLLEGE, MILE END ROAD, LONDON, E.1. [*Received, September 27th*, 1954.]

Solvent Participation in Nucleophilic Displacement Reactions. Part II. The Reaction between Ethanol and Acid Chlorides.*

By R. F. HUDSON and B. SAVILLE.

[Reprint Order No. 5760.]

The kinetics of the reaction between alcohol and *p*-nitrobenzoyl and acetyl chlorides have been compared in a non-polar solvent (carbon tetrachloride) and a donor solvent (ether). In the former the order with respect to alcohol approaches three in dilute solutions and unity in concentrated solutions, whereas in ether the rate remains proportional to the square of the alcohol concentration.

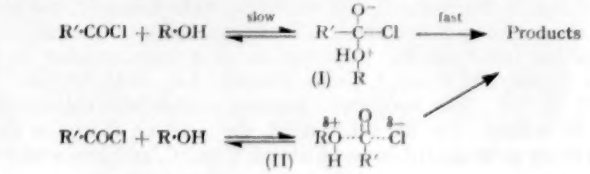
These results are interpreted by assuming the reaction to occur with trimeric associates in carbon tetrachloride, the concentration of which may be obtained from infrared data, and with two alcohol molecules in ether. The relative reactivity of the assemblies $(ROH)_3$ and $(ROH)_2$ in carbon tetrachloride and ether respectively is shown to be given by the statistical factor for the different number of alcohol molecules in the two cases, simultaneous nucleophilic and electrophilic action being assumed.

The results in the more concentrated solutions suggest a negligible (additional) solvent effect, which is supported by the similarity of the third-order velocity constants in ether and acetone.

THE general considerations discussed in the preceding paper will now be examined experimentally for two extreme types of reaction controlled either by the bond-forming process (S_N2 type) or by the bond-breaking process (S_N1 type). The experiments now to be described deal exclusively with the alcoholysis of acid chlorides in solvents of varying polarity, as these reactions proceed at convenient speeds and are irreversible under these conditions. Although the exact mechanism of the alcoholysis is not known with certainty even in solvolytic media owing to the possibility of addition, it is generally agreed that the preliminary bond-forming process determines the rate (Hudson *et al.*, *J.*, 1950, 1729, 3259; 1953, 883, 888, 3352; Gold, Hilton, and Jefferson, *J.*, 1950, 3259; Baker, *Trans. Faraday*

* Part I, preceding paper.

Soc., 1941, **37**, 632; Hughes, *ibid.*, p. 613). Hence the process kinetically resembles an S_N2 substitution at a saturated carbon atom, although energetically stable intermediates may be formed in the subsequent steps of the reaction. As considerable solvation is necessary for reaction, charge separation must occur in the transition state. This may be due to the formation of a polar addition compound (I) as in the case of esters (Bender, *J. Amer. Chem. Soc.*, 1951, **73**, 1626; see Ingold, "Structure and Mechanism in Organic Chemistry,"



Cornell Univ. Press, 1953, p. 775) or to the recurrence of an S_N2 mechanism (II). The rate sequence R·COBr > R·COCl > R·COF (Archer, Hudson, and Wardill, *J.*, 1953, 888; Bevan and Hudson, *J.*, 1953, 2187) with relative rates similar to those of the corresponding saturated halides, shows that considerable separation of the C–X bond occurs (II) and the transition state is probably best represented as an intermediate between (I) and (II). For present purposes it is sufficient to assume that such a transition state is stabilised by solvation as in the case of a corresponding reaction at a saturated carbon atom.

The reaction is followed first in a non-polar solvent, as under these conditions solvent–transition state interaction will be at a minimum, and the preferential solvation by the more polar molecules will provide most of the solvation energy. There is some uncertainty over the reaction mechanism and even the kinetic order of reactions leading to ionic products in completely non-polar media as the reactions are frequently heterogeneous (Pickles and Hinshelwood, *J.*, 1936, 1353). These reactions become homogeneous in more polar solvents (*idem*, *loc. cit.*). The small activation energies show that such reactions are energetically favourable when only small solvation forces are available.

In solvents of low polarity the preferential solvation by the more "active" molecules frequently leads to integral kinetic orders (Swain, *J. Amer. Chem. Soc.*, 1948, **70**, 1119; Swain and Eddy, *ibid.*, p. 2989) and this has led to some controversy over the molecularity of the process. Following the recent suggestions of Gelles, Hughes, and Ingold (*J.*, 1954, 2918) and of Swain (*J. Amer. Chem. Soc.*, 1955, **77**, 1122) it is proposed to refer to the number of molecules of one kind solvating the transition state as the kinetic order of the solvation process, and retain the original definition of molecularity (Hughes and Ingold, *J.*, 1935, 252), since this differentiates between two extreme kinds of substitution mechanism.

Experimental

Purification of Materials.—Carbon tetrachloride (Hopkin and Williams, "AnalaR" grade) was refluxed for 4 hr. over phosphoric oxide and distilled through a Vigreux column. Absolute alcohol was distilled from quicklime and finally treated with magnesium and iodine before further distillation in the manner described by Vogel ("Practical Organic Chemistry," Longmans, Green, 1948, 170). Acetone was stored over potassium carbonate, distilled in a Towers distillation unit, and finally refluxed over phosphoric oxide before redistillation. Only small amounts were distilled as required, since water slowly accumulates on standing as shown by titrations with Karl Fischer reagent. Freshly distilled samples usually contained a maximum of 0·05% of water; they had b. p. 56·5°.

Ether was stored over sodium wire for at least a week and decanted on to freshly prepared sodium sand, over which it was refluxed for 2 hr. The ether was finally distilled through a Vigreux column and had b. p. 34·5°. Acetyl chloride and *p*-nitrobenzoyl chloride were purified by fractional distillation (Brown and Hudson, *J.*, 1953, 3352).

Kinetic Measurements.—The reactions were initiated by weighing the required quantity of acid chloride into 100 ml. of ethanol solution in a stoppered flask in a thermostat after temperature equilibrium had been obtained. A stop-clock was started at the same time, and the flask was shaken vigorously for a few seconds. Portions of 5 ml. were extracted at convenient times and added to 40 ml. of pure cold acetone to stop the reaction. The liberated

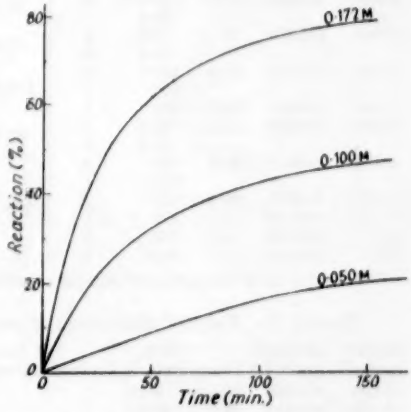
hydrogen chloride was titrated with 0·05N-triethylamine in toluene, Naphthylamine-orange being used as indicator.

A modified procedure was used for reactions with half-lives of the order of 1 min. or less. A solution of the acid chloride in the solvent alone, and a solution of twice the required concentration of alcohol were brought to the thermostat temperature; 5 ml. of the acid chloride solution were pipetted into a clean dry flask, 5 ml. of the alcohol solution rapidly added, and a stop-watch was started when the pipette was half empty. After an appropriate time, 40 ml. of cold dry acetone were rapidly added, thus stopping the reaction. The reaction mixture was then titrated as before, and the measurement repeated for other reaction times.

When ether was used as solvent the reactions were carried out in specially constructed vessels to allow samples to be withdrawn for analysis with minimum liquid surface exposed to the atmosphere, thus reducing evaporation losses.

Treatment of Experimental Results.—In the more concentrated solutions, *i.e.*, above *ca.* 0·5M, the rate of reaction is given accurately by a first-order equation from which a pseudo-unimolecular constant can be obtained directly. Results so obtained are denoted by *L* in the following Tables. In the more dilute solutions (0·05—0·34N-EtOH) the rate, as estimated by the variation in hydrogen chloride concentration with time, varies in a complex manner with alcohol concentration (Fig. 1), which may be due to one or more of the following causes: (1) The change in degree of association of alcohol as the concentration decreases in the course of the reaction (see p. 4127). (2) The change in the degree of association by interaction of alcohol with the products of reaction. (3) The loss of hydrogen chloride from the solution (in particular when carbon tetrachloride was used as solvent). This effect can usually be detected qualitatively, and leads to a sharp decrease in rate (Fig. 1).

FIG. 1.



For these reasons, attention was paid to the first part of the rate curve. Values of the initial rates were obtained from the slope of the % reaction–time curves in the first few % of the total reaction. This was taken as the instantaneous rate at the mean concentration over which the extrapolation was made. This method (denoted by " I " in the following Tables) gives pseudo-unimolecular rate constants comparable with the values obtained for higher concentrations.

First-order rate constants for the reaction in carbon tetrachloride were also obtained graphically from the rate curves by assuming that over the initial part of the reaction the reaction rate is given by $dx/dt = (a - x)(b^* - x)$, where a is the initial concentration of chloride, b^* the effective initial concentration of alcohol, and x the concentration of hydrogen chloride produced at time t. Then

$$\ln a/(a - x) = k\int_0^t (b^* - x)dt$$

At time t_1 when $x = x_1$ it follows that

$$\ln a/(a - x_1) = kb^*t - k\int_0^{t_1} x \,.\, dt = k(b^*t_1 - s_1)$$

and at time t_2 when $x = x_2$

$$\ln a/(a - x_2) = k(b^*t_2 - s_2)$$

where s_1 and s_2 are the areas under the curves of x against t. As $k_1 = kb^*$ it follows that

$$k_1 = [s_2 \ln a/(a - x_1) - s_1 \ln a/(a - x_2)]/(s_2t_1 - s_1t_2)$$

By choosing several pairs of x and t the constancy of k_1 can be investigated. This method of calculating k_1 is referred to as " A " in the following tables.

Results.—The rate was found to be almost proportional to the concentration of chloride for a constant ethanol concentration as shown by the results in Table 1. The rate curves were almost superimposable for the first 15% of the reaction in 0·172M-alcohol solution, after which the rate

reductions are more pronounced for the higher concentrations. This observation is important in that it indicates that the acid chloride does not form a complex with alcohol. If this were the case some change in the equilibrium constant with the concentration of acid chloride should be observed with a corresponding effect on the kinetics, unless of course the association is complete. In view of the incomplete association of the alcohol, this is unlikely, and in the following discussion preliminary association of alcohol and acid chloride will be neglected.

The effect of ethanol concentration on the rate of reaction of acetyl chloride is shown in Table 1, and of *p*-nitrobenzoyl chloride in Table 2. The internal consistency is of the order of 1—2% except in the most dilute solutions where the inaccuracy may be as high as 5%.

TABLE 1. *Rates of ethanolysis of acetyl chloride in carbon tetrachloride.*

[EtOH] (mole/l.)	[AcCl] (mole/l.)	Temp.	10^4k_1 (min.$^{-1}$)	Method	10^4k_1 (min.$^{-1}$), mean	[EtOH] (mole/l.)	[AcCl] (mole/l.)	Temp.	10^4k_1 (min.$^{-1}$)	Method	10^4k_1 (min.$^{-1}$), mean
0·050	0·0526	20·0°	23·8	A	23·2	0·172	0·0510	0°	114	A	114
			22·6	I		0·345	0·0502	20·0	952	I	
0·050	0·0516	20·0	23·4	A	23·4				969	A	
			23·4	I		0·345	0·0638	20·0	979	I	969
0·050	0·0520	0	15·4	I	15·4				979	A	
			15·4	A		0·345	0·0506	0	245	A	245
0·100	0·0520	20·0	122·5	A	122·5	0·690 *	0·0510	20·0	2290	L	2290
			124	I					2550	I	
0·100	0·050	20·0	121	I		0·690 *	0·0510	20·0	2310	I	
0·100	0·0496	0	63·2	A	62·5				2330	L	
			61·8	I		0·690 *	0·0521	0	497	L	497
0·172	0·0510	20·0	369	A	369	0·3193	0·0450	26·0	—	I	1170
			358	I		0·3193	0·0450	13·0	—	I	593
0·172	0·0570	20·0	372	A		0·2190	0·0436	26·0	—	I	701
0·172	0·0497	—	371	I		0·2190	0·0438	13·0	—	I	375
0·172	0·0235	—	364	I		0·1105	0·0430	26·0	—	I	189
0·172	0·0100	—	380	I		0·1105	0·0430	13·0	—	I	135

* In the most concentrated ethanol solutions k_1 was obtained from the first-order equation.

TABLE 2. *Rates of ethanolysis of* p-*nitrobenzoyl chloride in carbon tetrachloride.*

[EtOH] (mole/l.)	[R·COCl] (mole/l.)	Temp.	10^4k_1 (min.$^{-1}$)	Method	*E* (kcal./ mole)	[EtOH] (mole/l.)	[R·COCl] (mole/l.)	Temp.	10^4k_1 (min.$^{-1}$)	Method	*E* (kcal./ mole)
0·100	0·0489	20·0°	6·89	I	10·25	5·175	0·0465	20·0	1264	L	10·73
0·172	0·0485	20·0	20·5	I		5·175	0·0468	10·5	694	L	
0·690	0·0462	20·0	139	L		5·175	0·0465	0·0	319	L	
0·690	0·0551	10·5	80	L							
0·690	0·0499	0·5	40	L							

TABLE 3. *Activation energies for the alcoholysis of acetyl chloride in carbon tetrachloride solutions of varying alcohol concentration.*

[EtOH] (mole/l.)	E_{0-20} (kcal./mole)	[EtOH] (mole/l.)	E_{0-20} (kcal./mole)	[EtOH] (mole/l.)	E_{13-26} (kcal./lmole)	[EtOH] (mole/l.)	E_{13-26} (kcal./mole)
0·050	3·30	0·345	10·8	0·3193	8·95	0·1105	4·40
0·100	5·35	0·690	12·1	0·2192	8·18	—	—
0·172	7·6						

TABLE 4. *Ethanolysis of acetyl chloride and* p-*nitrobenzoyl chloride in donor solvents at* 20°.

[EtOH] (mole/l.)	[R·COCl] (mole/l.)	10^4k_1 (min.$^{-1}$)	[EtOH] (mole/l.)	[R·COCl] (mole/l.)	10^4k_1 (min.$^{-1}$)	[EtOH] (mole/l.)	[R·COCl] (mole/l.)	10^4k_1 (min.$^{-1}$)
Acetyl chloride in ether						*p*-Nitrobenzoyl chloride		
0·089	0·049	2·1 †	1·00	0·0503	136	0·345	0·050	2·44
0·172	0·050	4·8 †	1·725	0·0496	460	0·690	0·050	10·0
0·345	0·053	16·85	6·90 *	—	*ca.* 7000	3·450	0·038	244
0·690	0·048	61·8, 61·9 †				6·90 *	—	900

* Extrapolated from Branch and Nixon's results (*J. Amer. Chem. Soc.*, 1936, **58**, 2499).

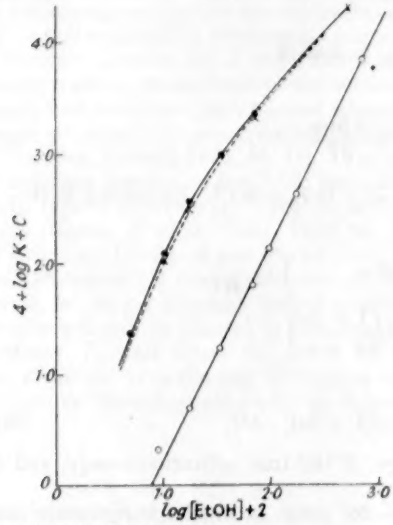
The activation energies were calculated from the Arrhenius equation (see Table 3), and the rate constants in ether and acetone are given in Table 4. The rate constants were obtained graphically from the first-order rate plots except when marked (†). The energy of activation for the ethanolysis of *p*-nitrobenzoyl chloride in 3·45M-ethanol in acetone was found to be 9·65 kcal.

Discussion

(A) *Reaction in Carbon Tetrachloride.*—The most characteristic feature of the kinetic results recorded in Tables 1 and 2 and Fig. 2 is the rapid change in apparent reaction order as the concentration of alcohol changes. Thus as the concentration of alcohol decreases, the order with respect to alcohol approaches 3, whereas above *ca.* 0·7M the order is almost unity. Over the same concentration range the temperature coefficient changes from very low values as the concentration of alcohol approaches zero to reach an almost constant value above 0·7M (Table 3).

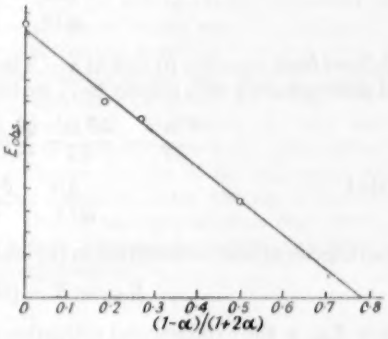
These regular changes are no doubt due to the association of alcohols in non-polar media. This association may be complex and the exact nature is not fully understood, but in the case of the simpler alcohols most measurements show that the smallest polymer which can be detected is the trimer (Hoffmann, *Z. phys. Chem.*, 1943, **53**, *B*, 179; Staveley and Spice, *J.*, 1952, 406; Mecke and Nückel, *Naturwiss.*, 1943, **31**, 348), and not the dimer as in the

Fig. 2.



○ AcCl in Et_2O, $c = 0$.
● AcCl in CCl_4, $c = 0$.
× p-NO_2·C_6H_4·COCl in CCl_4, $c = 1{\cdot}25$.
– – – – Superimposition of log [Trimers] (ordinate) + constant.

Fig. 3.



case of phenol and benzyl alcohol (Kreuzer and Mecke, *Z. phys. Chem.*, 1941, **49**, *B*, 309). Further association undoubtedly occurs as the alcohol concentration increases but the various equilibria may be represented by a common equilibrium constant (Lassettre, *Chem. Rev.*, 1937, **20**, 259; Kreuzer and Mecke, *loc. cit.*; Coggeshall and Saier, *J. Amer. Chem. Soc.*, 1951, **73**, 5414).

In the more dilute solutions (up to *ca.* 0·2—0·3M), the association may be satisfactorily described in terms of the monomer–trimer equilibrium only (Hoffmann, *loc. cit.*; Staveley and Spice, *loc. cit.*). It is significant that the kinetic order of the reactions studied changes over the concentration range where this equilibrium changes from one side to the other, and comparison with Hoffmann's data (*loc. cit.*) shows that the rate is proportional to the concentration of alcohol *in the associated state* over a wide concentration range (Fig. 2). It follows therefore that in the more dilute solutions reaction involves a group of three alcohol molecules either in the form of monomers or as a trimeric associate. Owing to the dynamic equilibrium between monomers and trimers, these two possibilities cannot be differentiated by kinetic measurements, and it is doubtful if there is any significant theoretical difference.

In the following discussion, reaction will be assumed to occur with a decomposing aggregate rather than a group of monomers, because this leads to a slightly simpler treatment when the more concentrated solutions are considered, and involves a more plausible picture of the reaction mechanism. The change in activation energy may be interpreted quantitatively on this basis as follows. From the mass-action equation,

$$\underset{C(1-\alpha)}{3\mathrm{ROH}} \rightleftharpoons \underset{\alpha C/3}{(\mathrm{ROH})_3}$$

it follows that

$$\alpha/(1-\alpha)^3 = 3C^2K \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(i)}$$

The reaction being assumed to occur between an aggregate and the alkyl or acyl halide, the rate is given by

$$-\mathrm{d[R'X]}/\mathrm{d}t = k_1[(\mathrm{ROH})_3][\mathrm{R'X}]$$

If $(\mathrm{ROH})_3$ is sensibly constant over the initial part of the reaction the observed pseudo-unimolecular constant k_0 is given by

$$k_0 = k_1[(\mathrm{ROH})_3] = k_1\alpha C/3$$

Logarithmic differentiation leads to

$$\frac{-E_{\mathrm{obs.}}}{RT^2} = \frac{E}{RT^2} + \frac{\partial \ln \alpha}{\partial T} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(ii)}$$

It follows from equation (i) that $\ln \alpha - 3 \ln (1-\alpha) = \ln K + \ln C^2$. Expanding $\ln (1-\alpha)$ and differentiating with respect to T, we have

$$\frac{\partial \ln \alpha}{\partial T} + \frac{3\partial \ln \alpha}{\partial T} \sum_0^\infty (\alpha + \alpha^2 + \ldots\ldots) = \frac{-\Delta H}{RT^2}$$

so that

$$\frac{-\Delta H}{RT^2} = \frac{\partial \ln \alpha}{\partial T} \cdot \left(\frac{1+2\alpha}{1-\alpha}\right)$$

Rearrangement and substitution in (ii) leads to

$$E_{\mathrm{obs.}} = E - [(1-\alpha)/(1+2\alpha)] \, . \, \Delta H \quad . \quad . \quad . \quad . \quad . \quad \text{(iii)}$$

where $E_{\mathrm{obs.}}$ is the experimental activation energy, E the true activation energy, and ΔH the heat of association of the trimer.

Values of $E_{\mathrm{obs.}}$ were obtained over the 13—26° range (a smaller temperature range could not be employed owing to the small temperature coefficient at the lower concentrations), and compared with the values of α obtained from Hoffmann's data (*loc. cit.*) at 20° (Table 5).

TABLE 5.

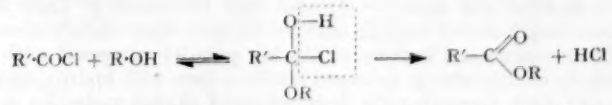
Ethanol (mole/l.)	—	0·3193	0·2192	0·1105
α	1	0·594	0·477	0·254
$(1-\alpha)/(1+2\alpha)$	0	0·186	0·267	0·495
E_0 (kcal./mole)	12·5	8·95	8·19	4·40

The value for $\alpha = 1$ was obtained by extrapolation of the E_0–[ROH] graph and is found to be equal to the value in 40% alcohol–ether solution (Branch and Nixon, *J. Amer. Chem. Soc.*, 1936, **58**, 2499). From the linear relation between $(1-\alpha)/(1+2\alpha)$ and $E_{\mathrm{obs.}}$ (Fig. 3) a value of ΔH of *ca.* 16 kcal./mole is obtained in agreement with the value of *ca.* 15 kcal./mole obtained spectroscopically by Mecke *et al.* (*loc. cit.*) and Hoffmann (*loc. cit.*) for simple alcohols.

A similar conclusion is reached if reaction is supposed to proceed with three monomers, the activation energy E' then being given by $E_{\mathrm{obs.}} = E' + [3\alpha/(1+2\alpha)]\Delta H$. The activation energy E' is negative in this case, and may be looked upon either as involving a pre-equilibrium as already considered, or alternatively as a result of the complexity of the transition state such that the heat content at this temperature is less than that of

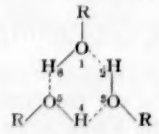
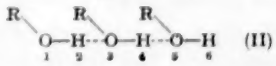
the reactants. In simple molecular terms this may be explained by regarding the nucleophilic attack and C–Cl bond stretching as activated processes assisted by an increase in temperature. The specific solvation will be non-activated in the sense that it is given approximately by simple electrostatic considerations. Hence increase in temperature will decrease this interaction by increasing thermal movement of the solvating molecules, and this effect may well be greater than the activation. The rate is measurable because of the very large entropy decrease accompanying a process of this kind.

It should be noted in passing that the present data in the most dilute solutions show that reaction does not proceed by elimination of covalent hydrogen chloride from an addition intermediate :



The results support the view already expressed (p. 4123) that the formation of the transition state is accompanied by considerable increase in polarity requiring further solvation.

The data given in Fig. 2 and Table 2 show that the rate of reaction of *p*-nitrobenzoyl chloride remains proportional to the concentration of alcohol in the associated state even though association proceeds beyond trimerisation. Before an explanation of this correlation is advanced, the properties and structure of the trimer will be briefly considered (see Davies, *Ann. Reports*, **1946**, **43**, 17). The preferential trimerisation may be attributed to the hydrogen bonding of two ROH molecules to each central molecule to give a cyclic or micelle type of structure (I). This explains the low polarity of the aggregate in non-polar liquids (Harms, *Z. phys. Chem.*, **1939**, **43**, *B*, 257), and the disappearance of the " free " OH frequency (Kempter and Mecke, *ibid.*, 1940, **46**, *B*, 229; Hoffmann, *loc. cit.*) which would be detected if the polymer were linear (II) as it probably is in more polar solvents (Harms, *loc. cit.*). Although further association increases the size of the aggregate, each molecule will still be bonded to two neighbours as shown by *X*-ray analysis (Pierce and MacMillan, *J. Amer. Chem. Soc.*, **1938**, **60**, 779). Then if reaction involves only three of these molecules as in the case of reaction with a trimer, further association may have no effect on the kinetics, as shown by the following considerations.

(I)   (II)

Reaction may then be regarded as involving the activation of one of the alcohol molecules by disruption of the hydrogen bond, so that oxygen atom (1) interacts with the carbon atom. As the hydrogen bond is now broken the hydrogen atom (2) simultaneously solvates the chlorine atom while oxygen atom (5) assists in the removal of the proton as the O–H bond breaks. The tendency for the molecule carrying oxygen atom (1) to become energised will be proportional to the number of molecules in the aggregate. Thus the total rate $= \sum_{n}^{\infty} kn[(\mathrm{ROH}_n)]$.

The concentration of alcohol in the associated state is given by $\sum_{n}^{\infty} n[(\mathrm{ROH})_n]$, so that the total rate is proportional to the concentration of alcohol in the associated state, as experimentally observed. There is no doubt that alternative formulations of the reaction mechanism may explain the observations, but the one adopted here is probably the simplest. Reaction with a decomposing aggregate rather than with individual monomers is preferred as the entropy change is more reasonable, as already indicated.

It follows from the above interpretation that the reaction proceeds specifically with a group of three ROH molecules irrespective of the size of the aggregate, and that the influence of the remainder of the solvent is negligible. This may be partly fortuitous in the more

concentrated solutions, but it should be realised that this close correlation is found for a chloride, the rate of which is controlled largely by bond formation. (*p*-Nitrobenzoyl chloride reacts strongly by an S_N2 type of mechanism.) Consequently, the life-time of the transition state is likely to be small compared with the time of relaxation of the alcohol molecules, as these are hydrogen-bonded to each other, thus reducing the probability of solvent molecules' orientating suitably. Moreover, the small general solvent effect may follow from the low polarity of the specifically solvated transition state as the charge separation in an S_N2 type of process may be relatively small (see Part I). This conclusion is supported by rate measurements in donor solvents which show that the rate of the third-order process * is only slightly affected by the polarity of the medium.

(B) *Reaction in Ether and Acetone.*—As seen from the results of Table 3 and Fig. 2, changes in alcohol concentration have an entirely different effect on rate when ether is used as solvent. Ether was chosen because of the low polarity compared with ethanol, and because the basicity enables strong hydrogen bonds to form with hydroxylic molecules (see Lassettre, *loc. cit.*), thus promoting the distribution of alcohol molecules in the medium. As the strength of an alcohol–ether bond is probably of the same order of magnitude as that of the hydrogen bond between two alcohol molecules, the latter may remain randomly distributed up to relatively high concentrations.

If this is the case, the observed kinetic order will be related directly to the number of molecules of a given kind (in this case ROH molecules) involved in the transition state. This is the case in polar solvents in which the hydroxylic molecules are separated by strong solvent–solute interaction. Thus the rate of the reaction between water and alkyl halides (Bateman and Hughes, *J.*, 1940, 942) and acyl halides (Crunden and Hudson, unpublished work) is proportional to the water concentration up to *ca.* 10% (v/v) in formic acid. Similarly the rate of solvolysis of Bu^{t}Br in nitromethane is proportional to the concentration of alcohol up to *at least* 10% (v/v) owing to electrophilic solvation (Gelles, Hughes, and Ingold, *J.*, 1954, 2918). These results suggest that changes in solvent structure (*e.g.*, as reflected in free volume, viscosity, etc.) produce relatively small effects on the rate, and may be regarded as secondary to the effect caused by concentration changes in the specifically solvating species.

The present results show that the rate of ethanolysis of acetyl chloride and *p*-nitrobenzoyl chloride in ether (and acetone) may be represented by the general expression

$$\text{Rate} = k_2[\text{R}'\cdot\text{COCl}][\text{R}\cdot\text{OH}] + k_3[\text{R}'\cdot\text{COCl}][\text{R}\cdot\text{OH}]^2 \quad . \quad . \quad . \quad \text{(iv)}$$

The first term is small in ether, so that the overall kinetics remain of third order over a wide range of concentration. This stoicheiometry supports the contention that the alcohol molecules remain more or less randomly distributed over a wide range of concentration.

The first term may be attributed to the rate of the bimolecular reaction with the transition state solvated by ether solvent. Owing to the shielding of the positive charges on the ether molecules, the electrophilic solvating power is small, so that $k_2 \ll k_3$. The second term represents the bimolecular rate with the transition state solvated by an alcohol molecule. A relation of this kind has been found to hold for other reactions in solvents where the specifically solvating molecules may be regarded as randomly distributed (Bartlett and Nebel, *J. Amer. Chem. Soc.*, 1940, **62**, 1345; Ashdown, *ibid.*, 1930, **52**, 268; Swain, *loc. cit.*).

Again, no decision can be made as to whether reaction proceeds with two ROH monomers coming together or with an activated aggregate of the kind R_2O–$(ROH)_2$. This difference is, however, trivial owing to the kinetic nature of liquid structure, and the rate may again be examined in terms of the concentration of these aggregates. In the more

* In donor solvents, *e.g.*, ether and acetone, solvation of the positive pole of the transition state can occur as readily as in alcohol, and hence the third alcohol molecule participating in non-polar media is not required. The overall kinetic order therefore decreases from 4 to 3. There is no evidence that removal or partial removal of the proton occurs in the transition state, and hence the third alcohol may not be necessary. If this is so it follows that reaction proceeds with trimers in carbon tetrachloride and not with three monomers, and that the third alcohol molecule is not involved in the rate-determining step. This point is being investigated.

dilute solutions, the probability of finding two ROH molecules together is given approximately by $(v_{ROH})^2/V^2$, *i.e.*, $(46/800)N^2$, where N is the molar concentration of alcohol. This gives approximately the concentration of $R_2O,(ROH)_2$ aggregates. The rates of reaction in carbon tetrachloride and ether containing equal concentrations of aggregates of the kind $(ROH)_3$ and $R_2O,(ROH)_2$ respectively are compared in Table 6.

TABLE 6.

[ROH] in ether	[(ROH_2)] in ether	k_{25} in ether	[ROH] * in CCl_4	k_{25} in CCl_4	$\frac{1}{3}\frac{k_{CCl_4}}{k_{ether}}$
Acetyl chloride					
0·345	0·0068	23·8	0·095	112·5	1·6
0·690	0·0270	123	0·187	405	1·1
1·00	0·575	369	0·300	825	0·8
1·725	0·170	949	0·670	2220	0·8
p-Nitrobenzoyl chloride					
0·345	0·0068	2·44	0·095	6·79	0·95
0·690	0·0270	10·0	0·187	24·2	0·8
Triphenylmethyl chloride					
0·828	0·0394	7·93	0·240	46	1·9
1·725	0·170	45·5	0·670	190	1·4

* Stoicheiometric concentration of alcohol in a solution in which the concentration of $(ROH)_3$ is equal to that of $R_2O,(ROH)_2$ in ether.

It is observed that in all cases where this comparison can be made, the rate of reaction with $(ROH)_3$ is of the order of three times as great as the rate with $R_2O,(ROH)_2$. A difference in reactivity of this order of magnitude may readily be attributed to the different number of alcohol molecules in the two aggregates. If it is assumed that simultaneous nucleophilic and electrophilic action are essential, the ratio of reactivities of the two aggregates is given simply by $2 \times 3 : 2 \times 1$, since the ether molecule can remove the proton as readily as the third alcohol molecule.

This close agreement supports the description of the reaction mechanism in carbon tetrachloride, and the conclusion that the effect of solvent on the specifically solvated transition state is negligible for these two reactions. The comparisons may be extended by comparing the rates of reaction of *p*-nitrobenzoyl chloride in acetone–alcohol and ether–alcohol mixtures. From the data given in Tables 3 and 4, it is readily seen that k_2 of equation (iv) is much greater in acetone than in ether, in agreement with the greater polarity of the medium. On the other hand, the value of k_3 in acetone is only approximately twice the value in ether, showing the small contribution of the solvent (other than the two alcohol molecules) to the solvation energy. This observation is in harmony with a previous observation that the rates of reaction of several acyl chlorides in 5% aqueous acetone and dioxan are almost equal in spite of the considerable difference in dielectric constant (Brown and Hudson, *J.*, 1953, 883). For this particular reaction, therefore, rates of reaction may be correlated over a wide range of solvents from non-polar to aqueous media.

It is considered that in such reactions the entropy decrease associated with the covalent interaction is sufficiently great to limit the specific solvation to one electrophilic group. It must be stressed, however, that the above simple treatment will only apply to suitable reactions, and that in general the stoicheiometry will not hold in concentrated solutions. For most bimolecular reactions, the stoicheiometry will break down in sufficiently polar solvents, *e.g.*, in highly aqueous solutions. Thus, although the present results suggest that the transition state structure of the alcoholysis of *p*-nitrobenzoyl chloride is unaffected by change in solvent over the range considered, a gradual change is observed in more aqueous solutions, accompanied by progressive increase in solvation (see Brown and Hudson, *J.*, 1953, 3352). This corresponds to a gradual change from the S_N2 type to the S_N1 type of mechanism which is considerably more advanced for other benzoyl chlorides (Brown and Hudson, *loc. cit.*; Gold *et al.*, *loc. cit.*; Crunden, M.Sc. Thesis, London, 1954).

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Solvent Participation in Nucleophilic Displacement Reactions. Part III. Ionisation Reactions with Particular Reference to the Alcoholysis of Triphenylmethyl Chloride.*

By R. F. Hudson and B. Saville.

[Reprint Order No. 5761.]

The high reactivity of triphenylmethyl chloride in the presence of electrophilic reagents and the very slow reaction with primary amines in carbon tetrachloride and in acetone suggest strongly that reaction involves preionisation. In carbon tetrachloride the rate is proportional to the concentration of associated alcohol over the 0·05—0·5M concentration range, showing that a minimum of three alcohol molecules are involved in the overall reaction.

In more concentrated solutions the rate increases rapidly with alcohol concentration, and this is attributed to further solvation of the initial ion-pair, which, however, remains associated as shown by the absence of mass-action repression of the rate. In contrast to the reaction of acid chlorides, the rate of reaction in dilute alcohol solutions is increased considerably by increase in the polarity of the solvent, *e.g.*, by replacing ether by acetone. Evidence is presented for a change in mechanism in acetone involving rate-determining substitution of the cation.

The kinetics of the ethanolysis of chlorodimethyl ether and 2 : 4 : 6-trimethylbenzoyl chloride have been followed in carbon tetrachloride and ether, and the influence of solvation has been discussed.

Triarylmethane derivatives are amongst the most readily ionised organic compounds, and stable salts have been known for a long time (see Burton and Praill, *Quart. Rev.*, 1952, **6**, 302). In addition, the covalent halides are rapidly ionised in polar aprotic solvents, *e.g.*, sulphur dioxide (Walden, *Ber.*, 1902, **35**, 2018) and nitromethane (Bentley, Evans, and Halpern, *Trans. Faraday Soc.*, 1951, **47**, 711). The ionisation of compounds of this type in non-polar media is strongly promoted by electrophilic reagents in benzene (Swain, *J. Amer. Chem. Soc.*, 1948, **70**, 1119; Hawthorne and Cram, *ibid.*, 1954, **76**, 3451). Recent observations have shown that ionisation occurs more readily than hitherto suspected. For example, 1-phenylethyl chloride is racemised by stannic chloride in carbon tetrachloride (Heald and Gwyn-Williams, *J.*, 1954, **362**), and 1-mesitylethyl chloride by acetone alone (Charlton and Hughes, *J.*, 1954, 2939). These observations suggest that ionisation may require a relatively small energy of solvation compared with earlier estimates (Evans, *Trans. Faraday Soc.*, 1946, **42**, 719), a view which is supported by the recent work of Swain and Kreevoy (*J. Amer. Chem. Soc.*, 1955, **77**, 1122) using ^{36}Cl ions. It was shown that in very dilute solutions of chloride ions in benzene, the exchange of Cl^- in triphenylmethyl chloride is of first order. The obvious inference is that the exchange follows a slow ionisation of the halide promoted by benzene solvent alone. It is therefore preferable to regard the ionisation as a covalent–ionic transition, as the energy of the ionic state must be lowered considerably by the electrostatic interaction between the two ions in intimate contact. This stabilisation energy (which may be of the order of 50 kcal./mole) is unimportant in systems leading to fully solvated ions.

The triarylmethyl cation is an exceptionally stable carbonium ion, and under some conditions where it is rapidly pre-formed the rate of substitution may be determined by the rate of the subsequent reaction with the nucleophilic reagent (Gelles, Hughes, and Ingold, *J.*, 1954, 2918). These workers have differentiated between such a case and the more frequent S_N1 process in which the slow ionisation controls the substitution rate.

In general, the ease of ionisation will be related simply to the stability of the cation as reflected in the ionisation potential. We are concerned here more closely with the significance of the kinetic order of the solvation process in various solvents in terms of the

* Parts I and II, preceding papers.

ease of ionisation. Most of the experimental results given below refer to the alcoholysis of triphenylmethyl chloride, as the kinetics are relatively simple in this case, but brief consideration is given to the solvent effect in other reactions which, at least in solvolytic media, are thought to proceed by rate-determining ionisation.

Experimental

The solvents were purified as in the previous paper and the same method of following the rate was used. Triphenylmethyl chloride (B.D.H.), recrystallised from light petroleum (b. p. 60—80°)–acetyl chloride (9 : 1), had m. p. 112°. " AnalaR " chlorodimethyl ether, purified by fractional distillation, had b. p. 59·5°. 2 : 4 : 6-Trimethylbenzoyl chloride was prepared and purified as given by Brown and Hudson (*J.*, 1953, 3352); it had b. p. 130°/22 mm.

Analysis of Results.—The reversibility of the reaction of triphenylmethyl chloride in ethanol–carbon tetrachloride mixtures is shown by the % reaction–time curves for various initial concentrations of ethanol (Fig. 1). Preliminary analysis showed that the rate is not given by the appropriate equation for a forward first-order and backward second-order process as expected for the reaction

$$Ph_3CCl + \underset{(excess)}{EtOH} \rightleftharpoons Ph_3{\cdot}COEt + HCl$$

In the more concentrated solutions (0·69—6·9M-ethanol) the pseudo-unimolecular rate constant k_ψ was found to obey a first-order reversal equation accurately * (Fig. 2) and hence k_1 could be obtained by assuming that $k_1 = k'T_e/T_\infty$, where k' is the experimental rate constant, T_∞ is the concentration of products equivalent to the initial concentration of triphenylmethyl chloride, and T_e is the corresponding concentration at equilibrium. For concentrations of ethanol less than 0·690M, the rate constants were obtained from initial rates, as the reaction does not follow the first-order rate equation accurately. A summary of the rate constants and position of equilibrium is given in Table 1. The accuracy is somewhat less than for the rate measurements of the acid chlorides, owing possibly to the reversibility of the reaction and the large molecular weight of the chloride. Change in concentration of the latter therefore has a significant effect on the medium. The change in rate constant with halide concentration is relatively small, and hence the reaction is approximately of first order with respect to this reactant. The results of Table 1 show that the graphical method used previously leads to significantly different results from the initial rates, and it was not used for this reaction.

The effect of temperature in the more concentrated solutions is given by the results in Table 2.

Table 1. *Ethanolysis of triphenylmethyl chloride in carbon tetrachloride at* 20·0°.

[EtOH] (mole/l.)	[R_3CCl] (mole/l.)	10^4k_ψ (min.$^{-1}$)	Method *	Equilibrium (% reaction)	[EtOH] (mole/l.)	[R_3CCl] (mole/l.)	10^4k_ψ (min.$^{-1}$)	Method *	Equilibrium (% reaction)
0·086	0·0093	6·1	I	23·8	0·345	0·0273	79·2	I	61·0
,,	0·0215	5·6	,,	18·2	,,	0·0250	86·0	A	60·7
,,	0·0333	5·7	,,	16·0	,,	,,	83·0	I	—
0·172	0·0110	25·0	,,	36·0	0·690	0·0250	197	I	75·0
,,	0·0473	27·1	,,	22·4	,,	—	203	E	—
,,	,,	30·0	A	—	1·380	0·0476	639	E	82·2
					2·412	0·0494	1725	L	—
					3·450	0·0470	3450	,,	—
					5·175	0·0480	8220	,,	—

* I = Initial rate method; A = graphical method; E = reversible first-order equation; L = first-order equation.

The following additional rate constants for reactions of triphenylmethyl chloride (0·025M) in acetone were obtained :

Hydrolysis in 1·11M-water in acetone at 21° : k_1 = 0·0847 (0·0856) min.$^{-1}$

The rates of reaction of 0·025M-*n*-butylamine and 0·025M-di-*n*-butylamine in acetone were too slow to be followed (less than 5% reaction detected in 24 hr.).

In the alcoholysis of 2 : 4 : 6-trimethylbenzoyl chloride and chlorodimethyl ether strong autocatalysis was detected in the more dilute solutions. This was shown to be due to the

* This is presumably due to the strong basicity of $Ph_3C{\cdot}OEt$ which associates preferentially with the HCl.

hydrogen chloride produced in the reaction. The extent of the autocatalysis can be defined in terms of the initial and the maximum rate of reaction. As shown by the results in Table 5 the variation between these two rates decreased with increasing concentration of alcohol and became negligible in solutions more concentrated than 1·0M.

TABLE 2. *Effect of temperature on the rate of ethanolysis of triphenylmethyl chloride in carbon tetrachloride.*

[EtOH] (mole/l.)	[Ph_3CCl] (mole/l.)	Temp.	10^4k_1 (min.$^{-1}$)	E (kcal./mole)	[EtOH] (mole/l.)	[Ph_3CCl] (mole/l.)	Temp.	10^4k_1 (min.$^{-1}$)	E (kcal./mole)
0·690	0·0250	20·0°	198	12·8	5·175	0·0480	20·0°	8220	13·6
,,	0·0248	10·3	97·8		,,	,,	10·8	3930	
,,	0·0251	0·0	41·1		,,	,,	0·5	1590	

TABLE 3. *Rate of isopropanolysis of triphenylmethyl chloride in carbon tetrachloride at 21°.*

[$CHMe_2$·OH] (mole/l.)	[Ph_3CCl] (mole/l.)	10^4k_1 (min.$^{-1}$)	Method	[$CHMe_2$·OH] (mole/l.)	[Ph_3CCl] (mole/l.)	10^4k_1 (min.$^{-1}$)	Method
0·657	0·0250	11·4	I	7·88	0·0250	585	E
3·94	,,	103	E			562	I
				13·14	,,	3480	E

TABLE 4. *Rates of ethanolysis of triphenylmethyl chloride and chlorodimethyl ether in semipolar solvents.*

[EtOH] (mole/l.)	[RCl] (mole/l.)	Temp.	10^4k_1 (min.$^{-1}$)	Method	[EtOH] (mole/l.)	[RCl] (mole/l.)	Temp.	10^4k_1 (min.$^{-1}$)	Method
Triphenylmethyl chloride in ether									
0·828	0·050	20·0°	7·93	E	5·175	0·052	20°	1040	L
1·725	0·051	,,	45·5	L	6·900 *	—	,,	6045	L
3·450	0·047	,,	281	L					
Triphenylmethyl chloride in acetone									
0·172	0·0250	21·0	62	I	0·690	0·025	21·0	507	E
0·345	0·0265	,,	173	I	0·690	0·025	0·5	92·6	E
			171	E	1·725	0·028	21·0	1445	L
Chlorodimethyl ether in ether									
0·690	0·050	20·0	1·16 †	I	5·175	,,	20·0	949	L
1·725	,,	,,	31·1	L	5·175	,,	,,	951	L
3·45	,,	,,	274	L				944	I
			266	I					

* Obtained from Nixon and Branch's results (*loc. cit.*).
† Slight autocatalysis observed.

TABLE 5. *Rates of ethanolysis of chlorodimethyl ether and 2 : 4 : 6-trimethylbenzoyl chloride in carbon tetrachloride at 20°.*

		10^4min.$^{-1}$		
[EtOH] (moles/l.)	[RCl] (moles/l.)	$\frac{dx/dt}{(a-x)} = k_1$ as $x \to 0$	$\frac{\partial x}{\partial t(a-x)}$ at $\frac{d^2x}{dt^2} = 0$ when $x = a$ *	a *
Chlorodimethyl ether				
0·050	0·0467	1·63	4·32	0·00598
0·100	0·0501	8·78	29·4	0·0100
0·172	0·0440	31·9	78·3	0·0136
0·345	0·0436	116	191	0·0166
0·690	0·0457	351	492	0·0228
2·59	0·0500	2820	—	—
2 : 4 : 6-Trimethylbenzoyl chloride				
0·172	0·0400	8·0	25·4	0·012
0·690	0·0400	132	168	0·020
2·59	,,	1670	1670	—
5·175	,,	7200	7200	—
5·175	,,	1140	1140	—

Owing to the complexity of the system, possible rate laws were not examined for these reactions.

Discussion

Reactions of Triphenylmethyl Chloride.—(a) *With dilute alcohol solutions in carbon tetrachloride.* Before an interpretation of the effect of solvent on the rate can be advanced, the mechanism of reaction under non-solvolytic conditions must be considered. Swain *et al.* (*loc. cit.*) described the mechanism in benzene as a termolecular process involving simultaneous nucleophilic and electrophilic solvation of the halide. These results are, however, inconclusive, as pointed out by Gelles, Hughes, and Ingold, (*loc. cit.*), and it is necessary therefore to investigate this reaction further.

The exceptional reactivity of triphenylmethyl chloride compared with aliphatic halides

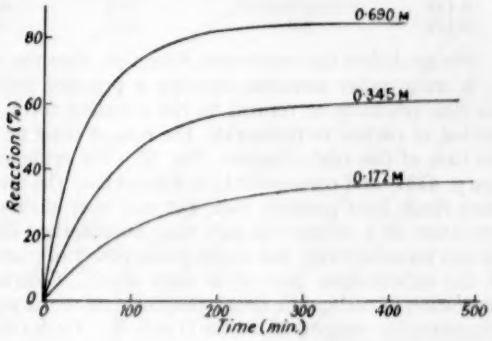


Fig. 1. *Rates of ethanolysis of* 0·025M-*triphenylmethyl chloride in* CCl_4–EtOH *solution.* (Concn. of EtOH given against corresponding curve).

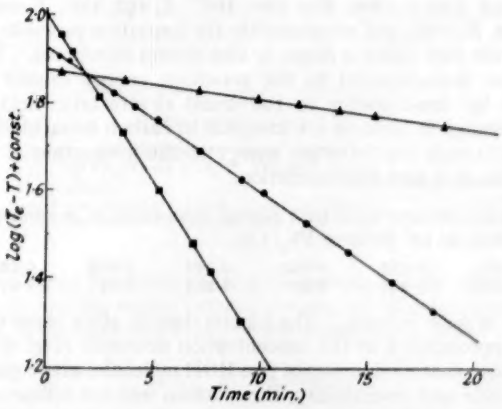


Fig. 2.

First-order reversal equation.

▲ 0·690M-EtOH, 0·025M-Ph_3CCl

● 1·380M- ,, 0·050M- ,,

First-order plot.

■ 2·412M- ,,

under these conditions suggests strongly that the driving forces in solvolytic and non-solvolytic media are similar, and further rate measurements with nucleophilic and electrophilic reagents support this view (Hudson and Saville, *Chem. and Ind.*, 1954, 1423). It is found that even in dilute solutions of alcohol in carbon tetrachloride, the addition of *n*-butylamine has a negligible effect on the reaction rate (see Table 6). The similar stereochemical configuration of the primary alcohol and amine discounts the possibility that steric hindrance prevents reaction in one case and not in the other. Neither can the lack of reactivity be attributed to the thermodynamic instability of the product as in the corresponding reaction of a tertiary amine (Ingold, " Structure and Mechanism in Organic Chemistry," Cornell Univ. Press, 1953, p. 356), since compounds of the type $Ph_3C{\cdot}NHR$ are normally prepared by heating triphenylmethyl chloride and the amine together in benzene.

As the influence of the amine would be much greater under these conditions than in solvolytic media, it follows that the substitution rate is not determined primarily by the

bond-forming process, *i.e.*, the reaction is probably not of the S_N2 type. On the other hand, the rate of alcoholysis and amination is increased considerably by electrophilic reagents, *e.g.*, phenol, as observed by Swain (*loc. cit.*), and the magnitude of the rate increases shows the dominating importance of the bond-breaking process.

TABLE 6. *The effect of electrophilic and nucleophilic reagents on the rate of reaction of triphenylmethyl chloride* (0·01—0·02M). Temp. = 20°.

[EtOH] (mole/l.)	Amine	10^4k (min.$^{-1}$)	[Phenol] (mole/l.)	Reactant	10^4k (min.$^{-1}$)
0·690	0·025M-NEt_3	178	0·10	0·10M-EtOH	1970
0·690	0·025M-Bu·NH_2	255	Nil	0·20M-EtOH	34·6
0·690	Nil	197	0·10	0·10M-BuOH	1590
0·172	0·023M-Bu·NH_2	22·3	0·10	0·10M-Bu·NH_2	6500
0·172	Nil	25	—	—	—

We are led to the conclusion, therefore, that the reaction proceeds by a slow ionisation, as in more polar solvents, forming a primary ion-pair which either decomposes to the reaction products or returns to the covalent form. In dilute solutions (up to 0·69M) of alcohol in carbon tetrachloride, the rate of reaction follows the trimer concentration as in the case of the acid chlorides (Fig. 3). No evidence of hydrogen-ion catalysis was found (see p. 4137) and consequently it follows that the reaction proceeds by interaction of at the most three (and possibly two, but not one) alcohol molecules to give the ion-pair. The formation of a similar ion-pair may be observed directly in dilute solutions of phenol in carbon tetrachloride; the nucleophilic power of phenol is low, and the equilibrium constant of the substitution process is very small. Colorimetric analysis indicated that the concentration of carbonium ions is proportional to the square of phenol concentration * over the concentration range 0·05—1·0M (Table 7). Under these conditions the associated phenol is largely in the form of dimers (Fox and Martin, *Proc. Roy. Soc.*, 1937, *A*, **162**, 419; Kreuzer and Mecke, *Z. phys. Chem.*, 1941, **49**, *B*, 309), and consequently the ionisation proceeds by the encounter of a molecule of chloride with either a dimer or two phenol monomers. The contribution of the solvent (carbon tetrachloride) to the solvation energy cannot be ascertained, but this is likely to be small owing to the small electrostatic field of the molecules. Thus salts which dissolve in benzene are insoluble in carbon tetrachloride, and it is probably satisfactory to attribute the solvation energy to the interaction of the two phenol or three alcohol molecules as a first approximation.

TABLE 7. *Change in carbonium-ion concentration with phenol concentration in carbon tetrachloride at* 18° (0·028M-Ph_3CCl).

Optical density at 410 mμ	0·018	0·029	0·084	0·192	0·358	0·425
[PhOH], M	0·0062	0·201	0·657	1·205	1·61	1·97

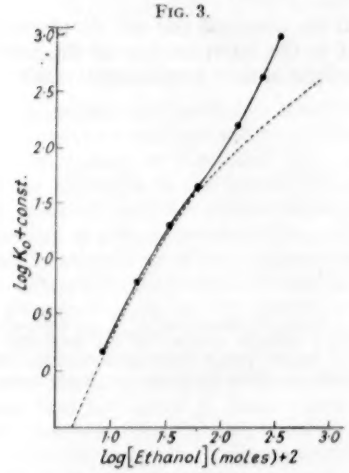
(b) *With dilute alcohol solutions in polar solvents.* The kinetic data in ether show that the order with respect to alcohol approaches 2 as the concentration decreases (Fig. 4), in agreement with the previous conclusion that a minimum of two ROH molecules are required for ionisation. Owing to the slow rate and reversibility, the reaction was not followed in solutions more dilute than 0·82M. The rate is increased considerably on changing to a more polar solvent; *e.g.*, the rate in acetone is of the order of 50 times greater than that in ether containing an equivalent alcohol concentration. This increase is attributed to the increased contribution of the solvent (acetone) to the solvation energy. This is in contrast to the corresponding reaction of *p*-nitrobenzoyl chloride (see Part II) as in this case the two rates are of the same order of magnitude. The difference lies in the greater polarity of the transition state of triphenylmethyl chloride which probably resembles an "intimate ion-pair" (see Winstein and Schreiber, *J. Amer. Chem. Soc.*, 1952, **74**, 2129).

The results of Table 4 show further that the apparent order in acetone is less than that in ether, and moreover this decreases with increasing alcohol concentration in contrast to the usually observed increase (*e.g.*, in ether) attributed to progressive solvation by hydroxylic molecules. The reaction in acetone probably involves a change in mechanism involving the

* Deduced by correlation of the results in Table 7 with the infrared data of Kreuzer and Mecke (*loc. cit.*). These systems are being investigated further.

nucleophilic process in the rate-determining step as recently detected by Gelles, Hughes, and Ingold (*loc. cit.*) for the reaction in nitromethane. Thus equimolar solutions of water and alcohol react at almost equal rates although water is a stronger electrophilic solvating agent. The rate with *n*-butylamine alone, however, remains low, so it may be inferred that the electrophilic process is the more important. There is no doubt that, by analogy with similar systems, ion-pairs are formed in acetone alone, but the concentration must be small compared with that of the electrophilically solvated species as shown by their low reactivity towards butylamine, itself a strong nucleophilic reagent. It may be concluded therefore that the mechanism is intermediate between that of *tert.*-butyl bromide and triphenylmethyl chloride in nitromethane (Gelles *et al.*, *loc. cit.*). Accordingly, the reaction is controlled

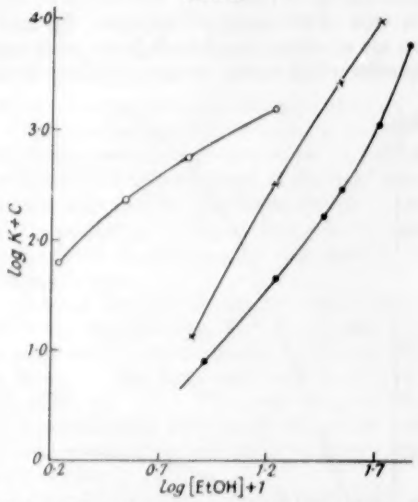
FIG. 3.



——— *Relation between rate of ethanolysis of* Ph_3CCl *in* CCl_4 *at 20° and ethanol concn.*

– – – – *Superimposition of log [Trimers] ordinate v. log* [EtOH] (*same abscissæ*).

FIG. 4.



Rate–concentration relationships for ethanolysis of:

○ 0·025M-Ph_3CCl *in* $COMe_2$ (c = 4).

× 0·050M-$CH_3Cl{\cdot}O{\cdot}CH_3$ *in* Et_2O (c = 5).

● 0·025M-Ph_3CCl *in* Et_2O (c = 4).

primarily by electrophilic action which has the effect of separating the ion-pair and hence reducing the rate of internal return (see Winstein and Schreiber, *loc. cit.*).

This mechanism may be represented as follows:

$$R'X + ROH \underset{k_3}{\overset{k_1}{\rightleftharpoons}} R^+ \ldots X^- \ldots HOR \xrightarrow{ROH;\ k_2} R'OR + H^+$$

In general, the solvated ion-pair can decompose internally or by reaction with a nucleophilic reagent. The second alternative is more likely, as the former process would be expected to proceed at a rate similar to that of the direct interaction of an ROH molecule with the ion-pairs stabilised by acetone alone. The participation of a second alcohol molecule being assumed, the rate is given by

$$-d[RX]/dt = k_1k_3[R'X][ROH]^2/(k_2 + k_3[ROH])$$

This explanation is supported by examining the change in apparent reaction order with alcohol concentration in terms of the relative nucleophilic and electrophilic reactivities of triphenylmethyl chloride towards water and alcohol given by Gelles *et al.* (*loc. cit.*). We have observed that the rates of reaction in 1M-alcohol and 1M-water solutions are approximately equal, hence it follows that

$$k_1k_3/(k_2 + k_3) = k_1'k_3'/(k_2 + k_3') \ (k \text{ refers to alcohol and } k' \text{ to water})$$

the assumption being made that the rates of internal return of the two ion-pairs $R' \cdots X \cdots HOR$ and $R' \cdots X \cdots HOH$ are equal. The results of Gelles *et al.* show that $k_3 = 4k_3'$, and if it is further assumed that the relative solvating power of water to alcohol is the same for triphenylmethyl chloride and *tert.*-butyl bromide, it follows that $k_1' = 2k_1$, and hence $k_2 = 2k_3'$.

The rate of the alcoholysis is then given simply by

$$-d[RX]/dt = 4k_1[ROH]^3/(1 + 2[ROH])$$

This enables the apparent order over a particular concentration range to be calculated. Over the 0·34—0·69M-alcohol range the observed and calculated orders are both 1·55; over the 0·69—1·725M-concentration range the experimental order is 1·12 compared with the predicted order of 1·29.

In view of the assumptions made, the fact that the observed and calculated reaction orders are of similar magnitude lends some support to this interpretation of the reaction mechanism which merits further investigation in the light of more experimental results. It

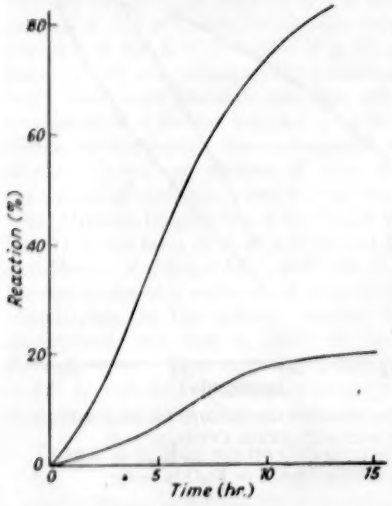


FIG. 5. *Rates of ethanolysis of* 2 : 4 : 6-*trimethylbenzoyl chloride* (0·05M) *in* 0·172M-EtOH *in* CCl_4 (*upper curve*) *and chlorodimethyl ether* (0·05M) *in* 0·050M-EtOH *in* CCl_4 (*lower curve*).

seems reasonable to conclude tentatively, however, that under these conditions the mechanism is intermediate between the two types of ionisation process designated S_N1 and S_{NO+} by Gelles, Hughes, and Ingold (*loc. cit.*).

(c) *With concentrated alcohol solutions.* As already mentioned, the rate of alcoholysis in carbon tetrachloride is proportional to the trimer concentration (or more strictly the concentration of alcohol in the associated form) in the more dilute solutions, but above 0·69M a strong additional solvent effect is observed (Fig. 3) in contrast to the corresponding reaction of the acid chlorides. This is in agreement with the previous observation that the rate increases considerably with increase in polarity of the solvent. Similarly, in ether the order of reaction with respect to alcohol increases regularly from *ca.* 2 in the dilute solutions to *ca.* 6 in the most concentrated solutions used (Fig. 4). Again the order of the corresponding reaction of *p*-nitrobenzoyl chloride remains 2 over most of this concentration range.

Although the order changes rapidly little change in activation energy is observed above 0·69M-ethanol, and again this limiting value is almost equal to that in alcohol–ether mixtures. This is perhaps surprising since further interaction between the medium and transition state would be expected to reduce the energy of the system (see Glasstone, Laidler, and Eyring, " Theory of Rate Processes," McGraw-Hill Book Co., 1941, Chapter 8). It may be significant that the activation energy in hydrogen-bonded solvents is approximately

equal to the sum of the heat of ionisation in nitromethane (Bentley, Evans, and Halpern, *loc. cit.*) and the energy of two hydrogen bonds, in view of the fact that a minimum of two ROH molecules are necessary for reaction.

The constancy of the activation energy above 0·69M with increasing kinetic order of the solvation process indicates a change in structure of the transition state or reaction intermediates, such that the additional solvation energy is compensated by an energy increase in the reacting system. Such a situation is possible if the additional solvent molecules solvate the primary ion-pair, thus effectively separating the ions further, and reducing the rate of internal return similar to the scheme of Winstein, Clippinger, Fainberg, and Robinson (*Chem. and Ind.*, 1954, 664) :

$$RX + (R'OH)_2 \rightleftharpoons (R^+X^-),3R'OH \overset{nR'OH}{\rightleftharpoons} R_n^+X^-$$

Products

No information on the relative effect on the rate of ionisation and subsequent substitution can be obtained but both will be affected. Owing to the high kinetic order of the reaction, however, it may be concluded that the additional solvation process must be important, and the reduction in the rate of return probably accounts for most of the rate increase. The relatively long life of the primary ion-pair increases its "collision radius," since all molecules of solvent or solute lying within a hypothetical radius r given $r = \bar{V}\tau$, were $\bar{V}$ is the mean velocity of the molecules and τ the life of the primary ion-pair, have a chance of colliding with the latter and stabilising the ion further.

Examination of the rate curves shows that the reaction in concentrated solutions is strictly of first order over the whole course of the reaction (Fig. 2). This shows that the solvated ion-pairs remain associated in concentrated alcohol solutions, whereas in aqueous acetone the ions are largely dissociated as shown by the large mass-action effect (Scott, Swain, and Lohmann, *J. Amer. Chem. Soc.*, 1953, **75**, 136). The latter observation also shows that the carbonium ion is stable when solvated by nucleophilic hydroxylic molecules, which further supports the interpretations of the reaction mechanism given above in terms of independent nucleophilic and electrophilic processes.

Chlorodimethyl Ether and 2 : 4 : 6-*Trimethylbenzoyl Chloride.*—Solvent participation was also examined in the alcoholysis of other reactive chlorides which are usually considered to react by an ionisation mechanism in solvolytic media. As already mentioned, triarylmethyl halides give exceptionally stable carbonium ions. This is reflected in the solvent effect in dilute alcohol solutions, as the relatively low energy required to ionise the halide enables the reaction to proceed in the presence of a small number of electrophilic molecules. In this case the high kinetic order in solvolysis may be attributed to the further solvation of the preformed ion-pair. As the C–X bond energy increases, however, one might expect that a greater number of hydroxylic molecules are necessary to provide the required solvation energy.

In order to examine this possibility, the effect of alcohol concentration on the rate of reaction of chlorodimethyl ether (Ingold, *op. cit.*, p. 333) and 2 : 4 : 6-trimethylbenzoyl chloride (Hudson and Brown, *J.*, 1953, 3352), which are normally considered to react by an ionisation mechanism, was determined. The rates of reaction are sufficiently great to be followed in dilute alcohol solution, and the reactions are largely irreversible, in contrast to the alcoholysis of tertiary alkyl halides. In carbon tetrachloride the measurements show that both reactions are strongly catalysed by acid (Table 5). The variation in initial rate with alcohol concentration is at least as pronounced as in the case of triphenylmethyl chloride, where no acid catalysis is observed. The autocatalysis becomes less pronounced as the alcohol concentration increases, and the initial rate becomes proportional to the square or cube of the trimer concentration. (It is realised that the associated alcohol is not in the form of trimers only in the concentration range under consideration, but it is convenient to refer to the order of the reaction in terms of trimer concentration for the purpose of comparison with the other reactions already considered.)

The general rate expression for these reactions therefore becomes of the form

$$-d[RX]/dt = k_1[RX]\{[HCl,nROH] + k_2[(ROH)_3] + k_3[(ROH)_3]^2 + \ldots\}$$

The participation of the second term cannot be detected in the present examples since the first term completely defines the rate in dilute solution as far as can be detected, and as the catalysis disappears the third term becomes important. In dilute solution, the reaction probably proceeds by proton transfer from a hydrogen chloride molecule which is itself solvated by a number of ROH molecules :

$$HCl + RX \xrightarrow{nR'OH} R^+ \ldots X^- \ldots H\text{–}Cl \xrightarrow{R'OH} \text{Products}$$

Similar catalysis has been observed in the hydrolysis of *tert.*-butyl bromide in acetone containing small quantities of water (Bateman, Cooper, and Hughes, *J.*, 1940, 913) but this rapidly gives way to a solvation process involving water molecules and acetone only, and in the racemisation of 1-mesitylethyl chloride (Charlton and Hughes, *loc. cit.*).

Similarly, in ether solution a minimum of three ROH molecules are required in the alcoholysis of chlorodimethyl ether under conditions where the acid catalysis is negligible. This reaction order is similar to that estimated from Böhme's results (*Ber.*, 1941, **74**, 248) for the hydrolysis of this chloro-ether and the thio-ether in dioxan. In neither case is there evidence for an increase in the kinetic order of the solvation process, which may be attributed to the instability of the carbonium ion formed :

$$R\text{–}O\text{–}CH_2\text{–}Cl \rightleftharpoons \begin{cases} R\text{–}\overset{+}{O}{=}CH_2 + Cl^- \xrightarrow{\text{Very fast}} \text{Products} \\ R\text{–}O\text{–}\overset{+}{C}H_2 \end{cases}$$

This also explains the irreversibility of this process, and the reaction of 2 : 4 : 6-trimethylbenzoyl chloride under similar conditions, as no mass-action repression is observed in 5% aqueous acetone (Brown and Hudson, *loc. cit.*).

In these reactions where several hydroxylic molecules are required to produce an (unstable) cation, the substitution process probably takes place without further separation of the ion-pair even in dissociating media. Reaction in the primary ion-pair may be recognised by the complete absence of mass-action repression of the rate, and by the lack of formation of the product of reaction with a highly nucleophilic reagent in the solvolysis medium. Thus strongly nucleophilic ions (*e.g.*, I^-, CNS^-, $S_2O_3^{2-}$) do not react to any appreciable extent with the *iso*propyl ion in aqueous acetone solution (Hudson and Marshall, unpublished work) and the hydrolysis of the tertiary butyl halides proceeds without mass-action repression (Bateman, Hughes, and Ingold, *J.*, 1940, 960). It has similarly been observed by Scott, Swain, and Lohmann (*loc. cit.*) that the competition factors (Ogston, *Trans. Faraday Soc.*, 1948, **44**, 45) of nucleophilic agents increase with the stability of the cation. The observations of Winstein *et al.* (*loc. cit.*) showing that the perchlorate ion interacts only with primary ion-pairs which are stabilised by neighbouring groups support the general interpretation.

This discussion shows that two kinetically distinct ionisation reactions may be recognised by studies of solvent participation, which correspond in general terms to the two mechanisms, termed S_N1 and S_{NO^+} by Gelles *et al.* (*loc. cit.*). These two mechanisms represent extreme cases of the general substitution process involving heterolytic bond fission, and differ mainly in the relative energy levels of ground state and intermediate cation. Thus a gradual change from one mechanism to the other is expected as in the corresponding transition from S_N1 to S_N2 mechanisms (Bird, Hughes, and Ingold, *J.*, 1954, 531; Winstein, Grunwald, and Jones, *J. Amer. Chem. Soc.*, 1951, **73**, 2700; Hudson and Brown, *loc. cit.*), depending on the structure of the reactant and on the relative nucleophilic and electrophilic power of the solvent.

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The Chlorination of Benzoic Acid in Aqueous System by Use of Oxidizing Acids.

By Hugh Y. Yee and A. J. Boyle.

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Benzoic acid is chlorinated in aqueous solution by means of sodium chlorate or potassium permanganate and hydrochloric acid. The oxidant in this reaction must have a redox potential above that of chlorine. Free chlorine is ineffectual. The presence of high chloride-ion concentration resulted in the greatest yield in the shortest time. It has been established experimentally that chlorinated quinones, formed during the reaction, result from oxidation of the benzoic acid before halogenation.

Two analogous chlorinations have been investigated, namely, Otto's original reaction (*Annalen*, 1862, **122**, 142) and one in which potassium permanganate was used in place of the potassium or sodium chlorate. The reactions were carried out with vigorous stirring at approximately 80°. The oxidant was added dropwise in aqueous solution during 70 min.

A 30% yield of *m*-chlorobenzoic acid was obtained from benzoic acid by using sodium chlorate, and a 50% yield by using potassium permanganate. Yields of crude product, which contained chlorinated quinones, were consistently 75—80%. The purification of this material was difficult. The method adopted involved hydrolysis of the quinone side-products with sodium hydroxide to a water-soluble compound which could be washed out after acidification. Recrystallization then gave the pure product.

The success of potassium permanganate and hydrochloric acid in the chlorination of benzoic acid, which does not appear to have been recorded, demonstrates that sodium chlorate and a chloride in acid media are not specific reagents for chlorination in Otto's reaction. In the majority of reactions, hydrochloric acid furnished both the chloride and the hydrogen ion; 20%-HCl was the best concentration. Less concentrated hydrochloric acid gives lower yields of *m*-chlorobenzoic acid, and much more slowly. The rate is markedly increased by concentrated hydrochloric acid but its use is impracticable because of the gross loss of hydrogen chloride gas at the reaction temperature. On replacement of hydrochloric acid by chlorine gas in combination with the equivalent amounts of sodium chlorate or potassium permanganate in sulphuric acid, little or no chlorination occurred. Use of hydrochloric acid and molecular chlorine was likewise unsuccessful. It appears that chlorination is effected only when chlorine is liberated *in situ*.

Attempts to chlorinate the various monochlorobenzoic acids resulted in 98% recovery of the *p*-chloro-, 93% recovery of the *m*-chloro-, and partial chlorination of the *o*-chloro-isomer, and no quinone-like by-products. A similar result was obtained with 3 : 4-dichlorobenzoic acid. It is therefore concluded that the chloranil and other chlorinated by-products must be formed from the benzoic acid and not from the chloro-acids.

Oxidation of a 1 : 1 mixture of benzoic and *m*-chlorobenzoic acid with potassium permanganate and sulphuric acid showed that 75% of the *m*-chlorobenzoic acid could be recovered but only 25% of the benzoic acid, the products being carbon dioxide and chlorine. Sultanor [*J. Gen. Chem.* (*U.S.S.R.*), 1946, **16**, 1835] has demonstrated the relatively high thermal stability of the chlorobenzoic acid. By greatly prolonging the reaction time in the halogenation of benzoic acid by these reagents there is further chlorination: a reaction time of several days, and use of increased amounts of sodium chlorate and hydrochloric acid, resulted in the formation of (unidentified) dichlorobenzoic acids. Separation either as barium salts or by chromatography (Marvel and Rands, *J. Amer. Chem. Soc.*, 1950, **72**, 2642) failed.

From the evidence it would appear that the chloranil is formed by decarboxylation of benzoic acid and chlorination of the resulting benzoquinone. Analysis of the gaseous products of chlorination of benzoic acid revealed considerable quantities of carbon monoxide, but there are several possible sources for this.

Experimental

Preparation of m-*Chlorobenzoic Acid.*—(*a*) Potassium permanganate (9 g.) in water (200 ml.) or (*b*) sodium chlorate (3·7 g.) in water (100 ml.) was added during 60—75 min. to benzoic acid (12·2 g.) and 5·5N-hydrochloric acid (200 ml.) stirred under reflux at 80—90°. After a further 30 minutes' stirring the mixture was cooled and the pale orange product collected, washed, and dried (12 g.; m. p. 125—140°). This was dissolved in the minimum amount of 10% sodium hydroxide solution, and the solution was filtered, diluted, and acidified with 20% sulphuric acid. The precipitate was collected and most of the pink colour (chloranilic acid) was washed out with water. Recrystallisation from aqueous alcohol (charcoal) and then benzene gave *m*-chlorobenzoic acid (7·5 g.), m. p. and mixed m. p. 157—158° (Found: C, 53·3; H, 3·3. Calc. for $C_7H_5O_2Cl$: C, 53·7; H, 3·2%).

Oxidation of a 1 : 1 *Mixture* (*by wt.*) *of* m-*Chlorobenzoic Acid and Benzoic Acid.*—The finely ground mixture (5 g.) was refluxed with potassium permanganate (15 g.) and 25% sulphuric acid (150 ml.) overnight, then extracted with ether, and the ether evaporated to give 2·52 g. of mixed acids (Found: equiv., 147, 146. Calc. for 75% $C_7H_5O_2Cl$ + 25% $C_7H_6O_2$: equiv., 147·9).

Prolonged Chlorination of Benzoic Acid.—In a 3-l. round-bottomed flask fitted with a reflux condenser are placed benzoic acid (20 g.) and concentrated hydrochloric acid (1200 ml.). A solution of sodium chloride (53 g.) in water (300 ml.) is added in 10-ml. quantities at 10-min. intervals, and the mixture refluxed for 6—7 days. The clear supernatant liquid is decanted from the dark orange oil. Upon cooling, about 20 g. of dichlorobenzoic acid are obtained, a further 9 g. (total yield 92%) being obtained from the oil by the procedure used in the removal of chloranil from *m*-chlorobenzoic acid (Found: equiv., 190, 198. Calc. for $C_7H_4O_2Cl_2$: equiv., 191).

Test for Carbon Monoxide evolved in the Chlorination.—The apparatus is that used in the preparation of *m*-chlorobenzoic acid but instead of the reflux condenser is a tube leading consecutively into two gas wash-bottles containing arsenious oxide (10 g.) and sodium hydroxide (21 g.) dissolved in water (200 ml.), two drying towers containing phosphoric oxide, a U-tube containing iodine pentoxide heated to 150° by an oil-bath, and a 250-ml. suction flask containing a solution of starch and potassium iodide. A water aspirator is attached to the last container and gentle suction is maintained. The reaction flask is heated to 80—90°, and air drawn through the system for 45 min. as a test for the iodine pentoxide which is first purified by Vandaveer and Gregg's method (*Ind. Eng. Chem. Anal.*, 1929, **1**, 129). Potassium permanganate is then added and, *ca.* 20 min. after the first addition, a blue colour appears in the starch solution, indicating the presence of carbon monoxide. Its presence was also proved by running the gases through fresh blood instead of iodine pentoxide and the starch–iodide indicator, and application of the hæmoglobin test.

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Thermodynamics of Hydrocarbon Mixtures. Part I. The Heats of mixing of the Binary and Ternary Systems formed by Benzene, cycloHexane, and n-Heptane.

By C. P. Brown, A. R. Mathieson, and J. C. J. Thynne.

[Reprint Order No. 6416.]

The heats of mixing of the systems benzene–*cyclo*hexane, benzene–*n*-heptane, *cyclo*hexane–*n*-heptane, and benzene–*cyclo*hexane–*n*-heptane have been determined at 20°. The results for the binary systems show deviations from the theory of strictly regular solutions. The determined heats of mixing are compared with those calculated from vapour-pressure data, and the interchange energies estimated at different temperatures. The solubility parameters calculated from the heats of mixing are not in agreement with those given by Hildebrand. The results for the ternary system are quite well represented by the equations of Scatchard, Goates, Ticknor, and Macartney (*J. Amer. Chem. Soc.*, 1952, **74**, 3724) and Redlich and Kister (*Ind. Eng. Chem.*, 1948, **40**, 341) which relate the heats of mixing in ternary and binary systems.

A knowledge of the thermodynamic properties of multicomponent hydrocarbon mixtures is important in many large-scale industrial processes, but detailed experimental investigation of the very large number of complex systems involved is clearly impossible. The prediction of the properties of a multicomponent system from the behaviour of its constituent binary mixtures would be a very significant advance. Scatchard, Wood, and Mochel (*J. Amer. Chem. Soc.*, 1940, **62**, 712) suggested an equation to predict the free energies of ternary mixtures from their constituent binary mixtures, which was modified by Redlich and Kister (*Ind. Eng. Chem.*, 1948, **40**, 341) and later tested experimentally by Scatchard, Goates, Ticknor, and Macartney (*J. Amer. Chem. Soc.*, 1952, **74**, 3724) for the system methanol–carbon tetrachloride–benzene. Tsao and Smith ("Applied Thermodynamics," Chem. Eng. Prog. Symp. Series No. 7, 1953, **49**, 107) have recently measured the heats of mixing of the ternary system methanol–*n*-heptane–toluene and the appropriate binary systems and suggested a method for predicting ternary heats of mixing data from binary systems. None of these results refers to a mixture of non-polar hydrocarbons.

Further data are needed to test the recent theories of liquid mixtures, and non-polar hydrocarbon mixtures which show relatively small deviations from ideality are very suitable for this purpose. Consequently, measurements of the heats of mixing and the vapour pressures of selected binary and ternary hydrocarbon mixtures should be of practical and theoretical interest. This paper reports the heats of mixing of the binary and ternary systems formed by benzene–*cyclo*hexane–*n*-heptane. The volume changes on mixing and the vapour pressures are also being measured, and the work is being extended to include other systems.

Experimental

An apparatus designed to measure small heats of mixing accurately must incorporate efficient mixing and stirring and accurate temperature measurement; the vapours must not be allowed to mix, for, even if data are available to make corrections, this reduces the accuracy of the results (van der Waals and Hermans, *Rec. Trav. chim.*, 1950, **69**, 949). Many previous workers ignored this, for instance Hirobe (*J. Fac. Sci. Tokyo Univ.*, 1925, **1**, 155), Vold (*J. Amer. Chem. Soc.*, 1937, **59**, 1515), and Tsao and Smith (*loc. cit.*), but the mixing vessels used by Cheesman and Whitaker (*Proc. Roy. Soc.*, 1952, *A*, **212**, 406) and Scatchard, Goates, *et al.* (*loc. cit.*) both overcome this difficulty.

Calorimeter.—This consists of three concentric Dewar vessels, the innermost containing carbon tetrachloride (250 ml.) surrounding the mixing vessel itself, a platinum resistance thermometer, and an electric heating coil. The middle Dewar vessel holds alcohol which is kept within $\pm 2°$ of the temperature of the inner Dewar vessel by means of a heating coil and a

12-junction copper-constantan thermocouple. The outer Dewar vessel contains lagging, and the whole calorimeter rests in a lagged metal cylinder, 90 × 36 cm. The inner Dewar vessel is closed by a rubber stopper and the other two by wooden lids with rubber gaskets. The electrical leads and the ebonite stirrer shaft pass through the lids in air-tight sleeves.

Mixing Vessel.—This is made of brass, in two parts (Fig. 1). The lower cylinder, 3 × 8 cm., has three spikes (*I*) projecting upward from the base, and three vertical vanes (*G*) inside and outside to facilitate stirring. It has an external liquid-tight thread (*F*) at the top. The upper part consists of the lid, which has a Polythene gasket (*K*) and bears the vertical plunger sheath and a threaded sealed metal capillary tube (*D*) which can be removed to fill the vessel. The plunger (*C*) moves vertically in its sheath, and is liquid-tight when lubricated with Silicone grease.

Mixing and Stirring.—One liquid fills a thin glass ampoule which rests in the mixing vessel on the points *I*. The second liquid surrounds the ampoule and completely fills the mixing vessel. The point of the plunger rests on the ampoule, and breaking is effected by slightly depressing the plunger with a screw outside. The plunger also functions as an internal stirrer, since the plunger sheath is connected at the top by two metal strips (*A*) and a universal joint (*B*)

FIG. 1. *The mixing vessel.*

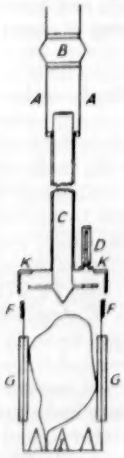
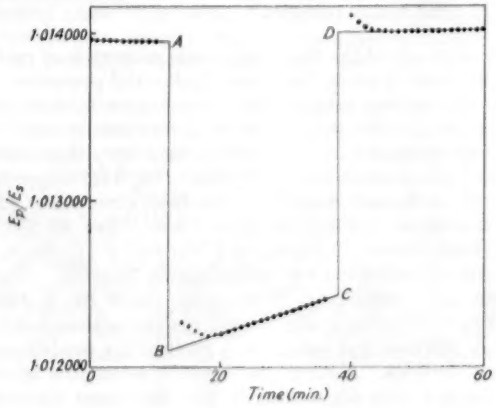


FIG. 2. *Typical mixing experiment for the system benzene–n-heptane. Mole fraction of benzene = 0·878. ΔH_m = 511 J/mole.*



to the ebonite stirrer shaft. The mixing vessel itself rotates and stirs the liquids both inside and outside it.

Electrical Circuits.—The sheath of the platinum resistance thermometer is of German silver, and the thermometer was calibrated at four fixed points, the carbon dioxide sublimation point, 0°, the transition temperature of sodium sulphate decahydrate, and 100°. The potential difference across the thermometer (E_p) is compared with that across a standard resistance (E_s) (27·6230 ω at 25°) by means of a Precision Vernier Potentiometer (Messrs. Pye Ltd.). A current of 5 mA flows through the circuit.

The heating coil consists of 170 cm. of constantan wire wound non-inductively on a mica former, with two copper leads from each end spot-welded to the constantan, and held in a flattened German silver tube filled with dry nitrogen at a pressure of $\frac{2}{3}$ atm. Current, which generally was allowed to flow for 2 min., is supplied for thermal calibration by four accumulators and the voltage drop across the coil is compared with that across a standard resistance (6·874 ω) at 25° by means of a Tinsley potentiometer.

Procedure.—The apparatus is assembled and allowed at least 3 hr. to attain thermal equilibrium. The temperature is measured every minute for 10—15 min. before mixing, the ampoule is then broken, and readings taken for a further 25 min. Mixing is complete in a matter of seconds. Current is passed through the heating coil for 2 min., having previously passed through an equal resistance for 2 hr., and the temperature measured every minute for a further period of 25 min. The temperature drop on mixing was always less than 0·6°, and the

rise on heating was always about 0·4°. Fig. 2 shows a typical mixing experiment, in which *AB* represents the temperature fall on mixing, and *CD* the rise on thermal calibration.

The concentration of the mixture is determined after the mixing experiment by measurement of its refractive index with an Abbé refractometer (Messrs. Hilger & Son, Ltd.), calibration curves of refractive index against mole fraction (x) having previously been determined. The ampoule and its contents are weighed before the experiment, and the broken glass is weighed afterwards. In conjunction with the refractive-index measurement, this enables the total mass of liquid to be determined.

Errors.—The reproducibility of the results for the heat of mixing, obtained from repeated experiments at the same concentration, was 0·7%. This is in agreement with the estimated total error due to the various factors involved, which is shown in Table 1. The rate of stirring had only a very small influence on the temperature, and it was maintained always at a constant rate which allowed the appropriate correction to be made by linear extrapolation.

TABLE 1. *Estimated errors.*

	Max. error (%)		Max. error (%)
Potential drop across platinum resistance thermometer	±0·004	Concentration measurement	±0·2
Potential drop across heating coil	±0·02	Non-mixing in the capillary	±0·002
Timing	±0·1	Stirring, always 80 r.p.m.	Negligible
Extrapolation of curves	±0·3	Evaporation	Negligible
	Maximum total error ±0·626		

Purity of Materials.—Benzene, of " AnalaR " grade, was shaken with concentrated sulphuric acid several times, washed with aqueous sodium carbonate and then with water, and dried ($CaCl_2$). It was fractionated through a 1½-m. column packed with glass helices. It was shown to be free from thiophen. *cyclo*Hexane, of B.P. quality, was treated with nitrating acid, then washed with aqueous sodium carbonate and water, dried ($CaCl_2$), and fractionated through the 1½-m. column. *n*-Heptane (Hopkin and Williams synthetic grade) was dried ($CaCl_2$) and fractionated through the 1½-m. column. Carbon tetrachloride was washed with alcoholic potassium hydroxide at 50—60° several times, shaken with water, and then shaken again with

TABLE 2. *Properties of the liquids.*

	B. p. (760 mm.)	F. p.	n_D^{25}	d^{25}
Benzene	80·10° (80·103°)	5·43° (5·506°)	1·4986 (1·49790)	0·87315 (0·87368)
*cyclo*Hexane	80·57 (80·738)	—	1·4237 (1·42354)	0·77382 (0·77389)
n-Heptane	98·40 (98·426)	—	1·3854 (1·38517)	0·67924 (0·67949)
Carbon tetrachloride	76·61 (76·71)	—	1·4587 (1·4573)	—

Values in parentheses are by Rossini, *J. Res. Nat. Bur. Stand.*, 1946, **36**, 129, except for CCl_4 which are from Grimm, *Z. phys. Chem.*, 1929, **2**, *B*, 181.

alcoholic potassium hydroxide three times. It was washed again with water, then with concentrated sulphuric acid, water, and alcoholic potassium hydroxide, and finally with water. It was dried (KOH), and fractionated in the 1½-m. column, the fraction which came over in the range 76·60—76·63° being collected.

The properties of the liquids are shown in Table 2.

Results and Discussion

Benzene–Carbon Tetrachloride at 25°.—A few experiments were made on this system to compare the results given by our apparatus and technique with those of Cheesman and Whitaker (*loc. cit.*) and of Hirobe (*loc. cit.*). Table 3 shows that the new results are in excellent agreement with the earlier figures.

TABLE 3. *Heat of mixing (ΔH_m) of benzene–carbon tetrachloride at 25° in joules per mole.*

Mole fraction of benzene (x_1)	0·318	0·736	0·817
Present value	96	82	64
Cheesman and Whitaker	95	84	65
Hirobe	98	84	64

Benzene–cyclo*Hexane at* 20°.—The heats of mixing (ΔH_{12}) per mole of mixture, expressed in absolute joules, are shown in Table 4.

TABLE 4. *Heat of mixing of benzene*–cyclo*hexane at* 20°.

Mole fraction of benzene (x_1) ...	0·100	0·215	0·245	0·250	0·300	0·595	0·700	0·785	0·870
ΔH_{12} (J/mole)	188	413	485	520	634	841	712	556	378

They fall on a smooth curve which is very slightly asymmetrical, the maximum value of ΔH_{12} occurring at $x_1 = 0{\cdot}535$. The best equation to fit the results is

$$\Delta H_{12} = x_1x_2[3350 + 590(x_1 - x_2) - 912(x_1 - x_2)^2] \quad . \quad . \quad . \quad . \quad (1)$$

where x_1 and x_2 are the mole fractions of benzene and *cyclo*hexane respectively.

Benzene–n-*Heptane at* 20°.—Table 5 shows the heat of mixing (ΔH_{13}) for this system. The plot of x_1 against ΔH_{13} is somewhat asymmetrical, the maximum value of ΔH_{13} occurring at $x_1 = 0{\cdot}560$. Equation (2) represents these data

$$\Delta H_{13} = x_1x_3[3841 + 1046(x_1 - x_3)] \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where x_3 is the mole fraction of *n*-heptane.

TABLE 5. *Heat of mixing of benzene*–n-*heptane at* 20°.

Mole fraction of benzene (x_1)	0·150	0·210	0·220	0·300	0·324	0·376	0·441
ΔH_{13} (J/mole)	436	546	584	742	772	823	902
Mole fraction of benzene (x_1)	0·511	0·588	0·650	0·715	0·828	0·878	
ΔH_{13} (J/mole)	945	948	928	857	629	511	

cyclo*Hexane*–n-*Heptane at* 20°.—The heat of mixing (ΔH_{23}) for this system is shown in Table 6. The plot is rather more asymmetrical than the others, the maximum value of ΔH_{23} occurring at $x_2 = 0{\cdot}590$.

TABLE 6. *Heat of mixing of* cyclo*hexane*–n-*heptane at* 20°.

Mole fraction of *cyclo*hexane (x_2)	0·230	0·310	0·378	0·444	0·480	0·540	0·617	0·730	0·830	0·893
ΔH_{23} (J/mole)	152	206	227	262	273	287	293	229	158	107

These results are best represented by equation (3):

$$\Delta H_{23} = x_2x_3[1121 + 268(x_2 - x_3) - 335(x_2 - x_3)^2] \quad . \quad . \quad . \quad . \quad (3)$$

Discussion of the Binary Systems: Comparison with the Theory of Regular Solutions.—The three binary systems all show small positive heats of mixing, which is to be expected from the nature of the components. The observed variation of the heats of mixing with composition is in only approximate agreement with the theory of strictly regular solutions proposed by Guggenheim (*Proc. Roy. Soc.*, 1935, *A*, **148**, 304). In this theory the "zero-th approximation" leads to an expression for the heat of mixing

$$\Delta H_m = x(1 - x)Nw \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

(where w is the interchange energy) which is of the same form as the first term in equations (1)—(3). The "quasi-chemical approximation" (Guggenheim, *loc. cit.*; Rushbrooke, *Proc. Roy. Soc.*, **1938**, *A*, **166**, 296) and Kirkwood's accurate series expansion (*J. Chem. Phys.*, 1938, **6**, 70) lead to equations of the form of (5) when only three terms are considered:

$$\Delta H_m = x(1 - x)Nw\left[1 - x(1 - x)\frac{2w}{zkT} - x(1 - x)(1 - 2x)^2\left(\frac{w}{zkT}\right)^2\right] \quad . \quad (5)$$

where z is the co-ordination number of the quasi-lattice. These equations result in symmetrical ΔH_m–x curves, but the experimental equations (1)—(3) are somewhat

asymmetrical. A tentative interpretation of this departure from strictly regular behaviour might be made in terms of a possible variation of w with composition, *i.e.*,

$$w_{x,1} = w_{0\cdot5} + p_1(x_1 - x_2) + p_2(x_1 - x_2)^2 + \ldots \quad (6)$$

(where p_1, p_2 are constants) which might be due to the differences in the molar volumes of the components.

Comparison with Vapour-pressure Data.—Vapour-pressure data are available for the systems benzene–*n*-heptane (Brown and Ewald, *Austral. J. Sci. Res.*, 1951, **4**, 198; 1952, **5**, 530) and benzene–*cyclo*hexane (Scatchard, Wood, and Mochel, *J. Phys. Chem.*, 1939, **43**, 119). The heat of mixing at 70° calculated from the vapour-pressure data is

$$\Delta H_{13} = x_1x_3[3005{\cdot}07 + 954{\cdot}89(x_1 - x_3) + 170{\cdot}15(x_1 - x_3)^2] \quad (7)$$

which is similar to equation (2) which refers to 20°. For benzene–*cyclo*hexane the corresponding equation, referring to 40°, is

$$\Delta H_{12} = x_1x_2[2929 - 97(x_1 - x_2) - 125{\cdot}5(x_1 - x_2)^2] \quad (8)$$

and at 70°

$$\Delta H_{12} = x_1x_2[2427 + 113(x_1 - x_2) + 25{\cdot}4(x_1 - x_2)^2] \quad (8a)$$

which may be compared with equation (1) at 20°.

The interchange energy w varies with temperature (Guggenheim, "Mixtures," Oxford Univ. Press, 1952, p. 83) and should be replaced by $[w - T\,\mathrm{d}w/\mathrm{d}T - T^2\,\mathrm{d}^2w/\mathrm{d}T^2]$ in all the equations. The second differential coefficient allows for the variation of ΔH_m with temperature which has been observed (van der Waals, Thesis, Gröningen, 1950; Cheesman and Whitaker, *loc. cit.*). The values of w, and average values of $\mathrm{d}w/\mathrm{d}T$ and $\mathrm{d}^2w/\mathrm{d}T^2$ calculated from equations (1)—(8), are shown in Table 7.

TABLE 7. *Interchange energy at* $x = 0{\cdot}5$ (J/*mole*).

	w (20°)	w (40°)	w (70°)	$\mathrm{d}w/\mathrm{d}T$	$\mathrm{d}^2w/\mathrm{d}T^2$ (42·5°
Benzene–*cyclo*hexane ...	3350	2929	2427	−21·05 (30°); −16·73 (55°)	−0·173
Benzene–*n*-heptane	3841	—	3005	−16·72 (45°)	—
*cyclo*Hexane–*n*-heptane	1121	—	—	—	—

Solubility Parameters.—According to Vold (*loc. cit.*),

$$\Delta\delta_{13} = \Delta\delta_{23} + \Delta\delta_{12} \quad (9)$$

where the δ's are the solubility parameters, and

$$\Delta\delta_{12}{}^2 = \left[\left(\frac{\Delta E_1}{V_1}\right)^{\frac{1}{2}} - \left(\frac{\Delta E_2}{V_2}\right)^{\frac{1}{2}}\right]^2$$

where ΔE_1, ΔE_2 are energies of vaporisation and V_1, V_2 molar volumes. Table 8 shows the values of $\Delta\delta$ calculated from the heats of mixing, together with those obtained by Hildebrand and Scott ("The Solubility of Nonelectrolytes," Reinhold, New York, 1950) from yapour-pressure measurements.

TABLE 8. *Solubility parameters.*

	$\Delta\delta$ (experimental)	$\Delta\delta$ (Hildebrand and Scott)
Benzene–*cyclo*hexane	2·85	0·95
Benzene–*n*-heptane	2·84	1·70
*cyclo*Hexane–*n*-heptane	1·46	0·75

For the three systems the experimental values are the larger. This is in conformity with the results of Cheesman and Whitaker (*loc. cit.*) and Vold (*loc. cit.*) on different systems. Equation (9) does not fit our data.

*Benzene–cyclo*Hexane–n-*Heptane at* 20°.—The ternary heats of mixing (ΔH_{123}) were determined by mixing the third component with binary mixtures at two or three different concentrations. Table 9 shows the experimental results for ΔH_{123} (J/mole of mixture) at 20° (column 4).

Equations have been suggested to allow the calculation of the heats of mixing of a ternary mixture from the heats of mixing of the three binary mixtures involved. Scatchard, Wood, and Mochel (*loc. cit.*) suggested an equation which was modified by Redlich and Kister (*loc. cit.*) to give

$$\Delta H_{123} \equiv x_1'x_2'\,[H_{12}' + H_{12}''(x_1' - x_2') + H_{12}'''(x_1' - x_2')^2 + \ldots.]$$
$$+ x_1'x_3'\,[H_{13}' + H_{13}''(x_1' - x_3') + H_{13}'''(x_1' - x_2')^2 + \ldots.]$$
$$+ x_2'x_3'\,[H_{23}' + H_{23}''(x_2' - x_3') + H_{23}'''(x_2' - x_3')^2 + \ldots.] \quad . \quad (10)$$

in which $\Delta H_{12} \equiv x_1x_2\,[H_{12}' + H_{12}''(x_1 - x_2) + H_{12}'''(x_1 - x_2)^2 + \ldots.]$ etc.

TABLE 9. *Ternary heats of mixing.*

x_1' (C_6H_6)	x_2' (C_6H_{12})	x_3' (C_7H_{16})	ΔH_{123} obs.	ΔH_{123} calc. from equation 10	11	12	x_1' (C_6H_6)	x_2' (C_6H_{12})	x_3' (C_7H_{16})	ΔH_{123} obs.	ΔH_{123} calc. from equation 10	11	12
0·312	0·392	0·296	816	895	820	1064	0·856	0·083	0·061	489	482	479	320
0·369	0·363	0·268	912	941	877	1064	0·836	0·095	0·069	548	539	533	360
0·270	0·418	0·311	737	828	767	1024	0·480	0·228	0·292	954	936	894	992
0·327	0·387	0·286	880	901	838	1069	0·501	0·195	0·304	946	1003	965	962
0·270	0·555	0·175	765	761	709	884	0·461	0·259	0·280	923	999	952	1031
0·335	0·505	0·160	818	851	800	938	0·595	0·250	0·155	904	946	918	835
0·302	0·530	0·168	798	809	756	917	0·639	0·195	0·166	856	916	894	765
0·818	0·138	0·044	553	547	547	407	0·616	0·223	0·161	904	934	909	802
0·774	0·172	0·054	628	651	645	502	0·298	0·280	0·422	819	895	809	1038
0·752	0·188	0·060	697	697	690	544	0·316	0·237	0·447	828	881	828	1018
0·809	0·145	0·046	582	568	567	423	0·232	0·191	0·577	715	724	682	867
0·817	0·139	0·044	570	557	549	423	0·462	0·380	0·158	949	971	919	967
0·810	0·070	0·120	649	637	632	459	0·415	0·342	0·243	957	972	917	1053
0·843	0·058	0·099	542	550	547	386	0·197	0·684	0·119	616	568	531	670
0·843	0·058	0·099	547	550	547	386	0·206	0·169	0·625	645	660	624	794
0·791	0·120	0·088	673	648	637	472							

Scatchard, Goates, *et al.* (*loc. cit.*) further modified equation (10) by replacing both $(x_1 - x_2)$ and $(x_1 - x_3)$ by $(2x_1 - 1)$. This modified equation (11) was originally intended to apply to mixtures containing one polar component, or for mixtures in which one component differs markedly in some way from the other two. Tsao and Smith (*loc. cit.*) suggested a slightly different equation (12) in which $x_1'x_2'$ is replaced by $x_2'/(x_2' + x_3')$, $x_1'x_3'$ by $x_3'/(x_2' + x_3')$, and $x_2'x_3'$ by $(1 - x_1')$ in equation (10).

Table 9 shows values of ΔH_{123} calculated from the binary data by equations (10), (11), and (12). Both equations (10) and (11) represent the ternary data quite well, showing average deviations of +2·1% and −1·9% respectively. Equation (12) gives a much poorer fit.

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The Magneto-optic Rotations of Some Two-component Liquid Systems.

By R. Fleming and L. Saunders.

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The work now described consists of the application of several mixture rules to two-component liquid systems in which the magnetic rotation of each component can be directly determined. The systems studied include an ideal system, a "pseudo-ideal" system, and two non-ideal systems. Each rotation recorded is the mean of 12 values determined at four magnetic field strengths, at each of which the direction of the field was reversed. Non-ideal systems are best described by the apparent molar volume rule.

Measurements of magneto-optic rotations are of interest in analysis and in the determination of molecular structure. The determination of the magnetic rotation of pure liquids is a simple matter, but in order to find the rotations of solids dissolved in liquid solutions, it is necessary to develop a satisfactory mixture rule. In the work now described several mixture rules were applied to two-component liquid systems in which the magnetic rotation of each component can be directly determined.

The earliest mixture rule for interpreting the magnetic rotation of two component systems was that of Verdet (*Ann. Chim. Phys.*, 1858, **52**, 129) who concluded that each component of a mixture behaves as if it alone were present in the total volume of the mixture. This rule remained unchallenged for many years, and it was not until 1928 that its validity was questioned by Schönrock (*Z. Physik*, 1928, **46**, 314; 1932, **78**, 707), who pointed out that the contribution of a component of a mixture to the total rotation was dependent on the volume of that component present, and that additivity of rotations was dependent on the additivity of volumes. Scharf (*Ann. Physik*, 1932, **13**, 377) modified Schönrock's rule since he found that it did not hold for solutions where there was appreciable volume change on mixing.

In this work five mixture rules have been examined. δ_i is the Verdet constant of a solution calculated according to Schönrock's rule: $\delta_i = \delta_1 q_1/s_1 + \delta_2 q_2/s_2$, where δ_i, δ_1, and δ_2 are the Verdet constants of the mixture, component 1, and component 2, respectively. The concentrations, q_1 and q_2, of the components are expressed in g./c.c., and s_1 and s_2 are their corresponding densities in the pure state. δ_{ii}, δ_{iii}, δ_{iv} are calculated according to volume-fraction rules $\delta_{ii} = \delta_1 V_1' + \delta_2 V_2'$, where V_1' and V_2' are volume fractions calculated from mole-fractions, N_1 and N_2, *e.g.*, $V_1' = N_1 V_1/(N_1 V_1 + N_2 V_2)$, where V_1 and V_2 are the molar volumes of the components. δ_{ii} is calculated by taking V_1 and V_2 as the molar volumes of pure components, δ_{iii} by using the partial molar volumes of the components, obtained from the plot of the total volume of one mole of mixture, $(N_1 M_1 + N_2 M_2)/d_4^{25}$, against N_2 by Lewis and Randall's intercept method ("Thermodynamics," McGraw Hill, New York, 1923, p. 38), and δ_{iv} by taking V_1, the molar volume of the solvent, as that of the pure liquid, whilst V_2 is taken as the apparent molar volume, ϕ_2, $\phi_2 = (V - n_1 V_1)/n_2$; δ_v is calculated according to Waring, Hyman, and Steingiser's mole-fraction rule (*J. Amer. Chem. Soc.*, 1938, **60**, 2294), $\delta_v = \delta_1 N_1 + \delta_2 N_2$.

Experimental

Apparatus.—The coil was built according to the specifications of Foehr and Fenske (*Ind. Eng. Chem.*, 1949, **41**, 1956); a battery selector switch was incorporated and this gave four main values of field strength. A network of four high-vacuum switches (Sunvic F105/5M) was used to reverse the direction of the current. The current source consisted of four heavy-duty Exide batteries, and the current strength was measured to 0·01 amp. by using a Cambridge T pattern, unipivot galvanometer. The rotations were read to 0·01° on a Bellingham and Stanley Class A polarimeter. A sodium light source was used throughout all the experiments. The heat developed when current passed through the coil was considerable, and it was necessary to have two water cooling systems. Water at 24·5° was passed through a cooling annulus incorporated in the coil; and water at 25° was passed through a specially adapted water-jacketed polarimeter

cell which fitted in the core of the coil and held the sample under test. The temperature of the water was measured immediately before and after passing through the jacket.

Magnetic rotations were measured at 4 main values of field strength, corresponding to 4 battery selector switch positions. At each main value of field strength, 12 readings of the magnetic rotation of the sample were taken, 6 for each direction of the current through the coil. In all, 48 readings were taken for each sample and these were averaged, and from the average result was subtracted the rotation of the cell end-plates. Knowing the value of the field strength per amp., and the length of sample, the magnetic rotation was converted into a Verdet constant.

The field strength of the coil was determined by measurement of the magnetic rotation of carefully purified substances whose Verdet constants are reported in the literature, *e.g.*, water, benzene, and carbon disulphide. The average value of field strength was found to be 163·10 ± 0·05 gauss/cm. amp., or 164·6 ± 0·30 gauss/cm. amp. according to Waring and Custer's new absolute values of the Verdet constants of water and benzene (*ibid.*, 1952, **74**, 2506; 1952, **74**, 5726). The former value was used to calculate the Verdet constant of the solutions.

Densities were determined in a Perkin-type pycnometer, and refractive indices were measured on an Abbé refractometer at 25°. The length of the polarimeter cell was measured with a Cambridge measuring machine.

Materials.—The water used was of conductivity standard. " AnalaR " benzene was further purified by fractional distillation and fractional freezing. The portion used for standardisation of the field strength had n_D^{25} 1·4977, d_4^{25} 0·8735, in close agreement with values given by Timmermans (" Physico-Chemical Constants of Pure Organic Compounds," Elsevier, London, 1950, p. 145). " AnalaR " carbon disulphide was fractionally distilled and had n_D^{25} 1·6237, d_4^{25} 1·2555.

Commercial ethyl bromide was purified by shaking it with concentrated sulphuric acid, followed by 10% sodium carbonate solution, and then with distilled water. The ethyl bromide was dried ($MgSO_4$) and fractionally distilled through a 46 cm. × 17 mm. fractionating column packed with Dixon gauze. The reflux ratio used was 25 : 1 and the boil-up rate 320 ml./hr. Only the middle fraction was collected and the values of $n_D^{15\cdot1}$ and $d_4^{15\cdot1}$ were 1·4276 and 1·4704 respectively, in close agreement with values given by Timmermans (*op. cit.*, p. 233). Ethyl iodide was also purified by fractional distillation at the same reflux ratio and boil-up rate; the values of n_D^{15} and d_4^{25} were 1·5168 and 1·9232 respectively. " AnalaR " pyridine was dried (KOH pellets) and then fractionally distilled; the middle fraction was collected and the values of n_D^{25} and d_4^{25} were 1·5071 and 0·9779 respectively.

Absolute ethanol was dehydrated according to a method described by Vogel (" Practica Organic Chemistry," Longmans Green, London, 1948, method 1, p. 165) and the values of n_D^{2} and d_4^{20} were 1·3592 and 0·7851 respectively. Nicotine, 95% (B.D.H.), was purified by a series of vacuum fractional distillations in a specially constructed, almost joint-free apparatus, and the fraction which boiled at 115°/12 mm. was collected. It was immediately sealed into ampoules under dry nitrogen, and the values of n_D^{25}, d_4^{25}, and $-[\alpha]_D^{25}$ were respectively 1·5250, 1·0042, and 168·54°.

Results.—The mixture rules have been used to calculate the Verdet constant of solutions belonging to the five following liquid–liquid systems: (1) ethyl bromide–ethyl iodide, an ideal system; (2) pyridine–ethanol, a " pseudo-ideal " system; (3) nicotine–ethanol; (4) pyridine–water, a non-ideal system; (5) sulphuric acid–water, a non-ideal system.

(1) *Ethyl bromide–ethyl iodide system.* Table 1 shows the results for this system. In this table, N_3 is the mole-fraction of ethyl iodide. The Verdet constants are in units of minutes of

TABLE 1. *Ethyl bromide–ethyl iodide system.*

N_3	$10^4\delta_D^{25}$	d_4^{25}	n_D^{25}	N_3	$10^4\delta_D^{25}$	d_4^{25}	n_D^{25}	N_3	$10^4\delta_D^{25}$	d_4^{25}	n_D^{25}
(EtI)	293·0	1·9232	1·5100	0·5741	247·3	1·7302	1·4760	0·1243	197·5	1·5125	1·4335
0·9349	286·3	1·8944	1·5043	0·4372	231·0	1·6645	1·4600	0·0612	190·1	1·4813	1·4272
0·8089	272·3	1·8395	1·4940	0·2785	214·5	1·5874	1·4470	(EtBr)	182·8	1·4490	1·4211
0·7250	262·7	1·7997	1·4862	0·1642	201·6	1·5313	1·4365				

Average divergence × 10^4: $\delta_I \pm 0{\cdot}74$; $\delta_{II} \pm 0{\cdot}74$; $\delta_{III} \pm 0{\cdot}74$.

angle/cm. gauss. The graph of the total volume of one mole of mixture plotted against the mole-fraction of ethyl bromide (N_1) is a linear curve (Fig. 1) showing that there is no volume contraction or expansion on mixing. The density of the mixtures plotted against the mole-fraction of ethyl bromide is shown in Fig. 2. There is a slight curve as required theoretically if Fig. 1 is linear with a finite slope. The average divergence between the Verdet constant of

the solutions calculated according to the mixture rules and the experimentally determined Verdet constant δ_D^{25} is shown.

(2) *Pyridine–ethanol system* (see Table 2). Recently Griffiths (*J.*, 1952, 1327) has found that the density–concentration curves are smooth and do not show any marked discontinuities. Blackburn and Kipling (*Nature*, 1953, **171**, 174) have found that this system is " pseudo-ideal," since the total and partial vapour pressures at room temperature approximate closely to the

TABLE 2. *Pyridine–ethanol system.*

N_2	$10^4\delta_D^{25}$	d_4^{25}	n_D^{25}	N_2	$10^4\delta_D^{25}$	d_4^{25}	n_D^{25}	N_2	$10^4\delta_D^{25}$	d_4^{25}	n_D^{25}
(C_5H_5N)	255·4	0·9779	1·5071	0·7408	225·9	0·9418	1·4786	0·2349	154·0	0·8471	1·4053
0·8880	243·2	0·9622	1·4950	0·5229	197·9	0·9054	1·4509	0·1264	135·6	0·8193	1·3855
0·8635	237·3	0·9564	1·4900	0·3061	165·8	0·8605	1·4171	(EtOH)	113·1	0·7851	1·3592

Average divergence $\times 10^4$: δ_I ±1·77; δ_{II} ±1·25; δ_{III} ±1·27; δ_{IV} ±0·6; δ_V ±1·00.

behaviour required by Raoult's law. The partial molar volumes of pyridine and ethanol, used to calculate the Verdet constants according to the partial molar volume mixture rule, were deter-

FIG. 1.

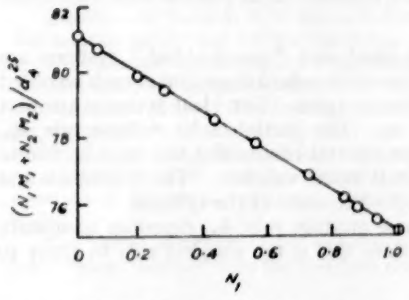
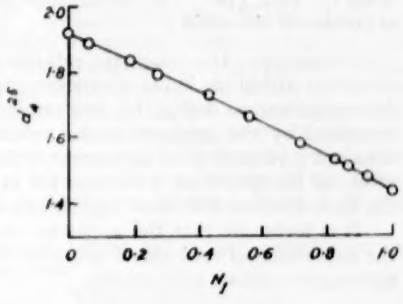


FIG. 2.



mined by the intercept method from the graph of the total volume of one mole of mixture plotted against the mole-fraction of pyridine.

(3) *Nicotine–ethanol system* (see Table 3). The Verdet constant of pure nicotine has been determined by Lowry and Allsopp (*J.*, 1932, 1617). The plot of $(N_1M_1 + N_2M_2)/d_4^{25}$ was a

TABLE 3. *Nicotine–ethanol system.*

N_2	$10^4\delta_D^{25}$	d_4^{25}	n_D^{25}	N_2	$10^4\delta_D^{25}$	d_4^{25}	n_D^{25}	N_2	$10^4\delta_D^{25}$	d_4^{25}	n_D^{25}
($C_{10}H_{14}N_2$)	228·8	1·0042	1·5250	0·4512	192·4	0·9419	1·4761	0·1274	145·6	0·8546	1·4120
0·8918	224·4	0·9971	1·5208	0·2602	170·2	0·9015	1·4447	0·1131	142·2	0·8479	1·4048
0·6142	208·2	0·9697	1·4993	0·1768	156·2	0·8741	1·4210	(EtOH)	113·1	0·7851	1·3592

Average divergence $\times 10^4$: δ_I ±1·21; δ_{II} ±1·34; δ_{IV} ±1·05; δ_V ±20·5

TABLE 4. *Pyridine–water system.*

N_2	$10^4\delta_D^{25}$	$10^4\delta_I$	$10^4\delta_{II}$	$10^4\delta_{III}$	$10^4\delta_{IV}$	$10^4\delta_V$	d_4^{25}	n_D^{25}
(C_5H_5N)	255·4	—	—	—	—	—	0·9779	1·5071
0·8941	250·9	252·8	252·1	252·8	252·1	242·5	0·9803	1·5031
0·6628	241·7	244·7	242·8	243·2	242·5	213·4	0·9892	1·4920
0·4816	230·3	234·7	231·0	232·5	230·7	190·9	0·9974	1·4782
0·3731	222·2	225·2	221·5	220·7	220·7	177·6	1·0010	1·4640
0·2875	209·3	214·8	210·9	211·2	210·0	166·6	1·0028	1·4491
0·2600	205·3	210·4	206·7	207·5	206·0	163·2	1·0032	1·4432
0·1909	196·0	198·3	194·9	195·3	194·2	154·4	1·0038	1·4295
0·0883	168·8	173·6	168·4	167·2	165·5	141·9	1·0025	1·3880
0·0539	154·8	157·3	155·9	154·8	155·1	137·5	1·0016	1·3690
(H_2O)	130·8	—	—	—	—	—	0·9971	1·3323
Average divergence		±1·8	±1·3	±1·3	±1·0	±32·4		

straight line, and so the partial molar volumes were equal to the molar volumes of the pure components.

(4) *Pyridine–water system* (see Table 4). Griffiths (*loc. cit.*) has shown that the density–concentration curve is smooth, and this agrees with our results. This system is non-ideal, and

the average divergences show clearly that the apparent molar volume mixture rule is the best one for calculating the Verdet constant of the solutions. There appears to be little advantage in using partial molar volumes in place of molar volumes; the Schönrock and the Waring mixture rule are unsatisfactory when the systems are non-ideal.

(5) *Sulphuric acid–water system* (see Table 5). Perkin (*J.*, 1893, **63**, 57) determined the magnetic rotation of sulphuric acid in water and found that the rotations of the mixtures were less than the sum of those of the constituents. The difference was considerable for small dilutions, but diminished as the amount of water increased. The molar volume of sulphuric

TABLE 5. *Sulphuric acid–water system.*

N_2	$10^4\delta_D^{25}$	d_4^{25}	n_D^{25}	N_2	$10^4\delta_D^{25}$	d_4^{25}	n_D^{25}
(H_2O)	130·8	0·9971	—	0·2883	120·5	1·5715	1·4150
0·0302	130·4	1·0970	1·3491	0·4953	114·6	1·7598	1·4347
0·0753	128·6	1·2218	1·3691	(98% H_2SO_4)	103·6	1·8310	—
0·1483	127·9	1·3772	1·3915	(H_2SO_4)	—	1·8269	—

Average divergence $\times 10^4$: $\delta_I = \pm 4{\cdot}4$; $\delta_{II} = \pm 3{\cdot}7$; $\delta_{III} = \pm 2{\cdot}9$; $\delta_{IV} = \pm 2{\cdot}2$; $\delta_V = \pm 1{\cdot}5$.

acid was calculated from the density of pure sulphuric acid as determined by Gillespie and Wasif (*J.*, 1953, 215). The partial molar volumes and apparent molar volumes were determined as previously described.

Conclusion.—The magnetic rotations of the ideal and "pseudo-ideal" systems are described within the limits of experimental error (mean standard deviation of each recorded determination = 0·4%), by any one of the mixture rules. Non-ideal systems are best described by the apparent molar volume rule, δ_{IV}. The partial molar volume rule, δ_{III}, does not give such good agreement with the experimental results and this may be due to errors in the graphical determination of the partial molar volumes. The Schönrock and the mole-fraction rule show large errors when applied to some of the systems.

It is fortunate that the apparent molar volume mixture rule, δ_{IV}, describes accurately the experimental rotation of non-ideal systems since this is the simplest rule to apply to systems containing solid solutes.

SCHOOL OF PHARMACY, UNIVERSITY OF LONDON. [*Received, May 24th*, 1955.]

The Magneto-optic Rotations of Two Ephedrine Isomers and Their Hydrochlorides in Solution.

By R. FLEMING and L. SAUNDERS.

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The volume fraction rule and the partial volume fraction mixture rule, described in the preceding paper, have been used to calculate the Verdet constants of two ephedrine isomers and their hydrochlorides. The higher Verdet constant for (−)-ephedrine suggests that the bonding forces between the molecules of this isomer are less than those between the molecules of ψ-ephedrine. This is in agreement with the differences of melting point, solubility, and volatility of the isomers.

THIS paper records the study of the magnetic rotations of (−)- and ψ-ephedrine in ethanol, and of the hydrochlorides of these bases in water. The Verdet constants of the solutes have been calculated according to two of the mixture rules previously described (*loc. cit.*), *viz.*, the volume fraction rule and the apparent volume fraction rule. For the purposes of the former rule the density of the solute was determined by the expression $\Sigma q/s = 1$, where q is the concentration of a component in g./c.c., and s is its corresponding density.

EXPERIMENTAL

Materials.—Commercial (−)-ephedrine hemihydrate was purified by recrystallisation from 70% ethanol, and dehydrated by vacuum-distillation; the distillate was allowed to crystallise in a vacuum to prevent the uptake of carbon dioxide and water vapour. The anhydrous base was further recrystallised from dry ether (Na dried).

ψ-Ephedrine was also purified by recrystallisation from dry ether, and its m. p. agreed with that quoted by Henry (" Plant Alkaloids," Churchill, London, 1949, p. 638). Commercial (−)-ephedrine hydrochloride was recrystallised from water until its m. p. agreed with that quoted by Henry (*op. cit.*, p. 636), and was assayed by using a strong anion-exchange column (Saunders, Elworthy, and Fleming, *J. Pharm. Pharmacol.*, 1954, **6**, 32). ψ-Ephedrine hydrochloride was recrystallised from ethanol and its m. p. agreed with that quoted by Henry (*op. cit.*, p. 638).

TABLE 1. *(−)-Ephedrine in ethanol.*

N_2	$10^4\delta_D^{25}$	$10^4\delta_2$ (ii)	$10^4\delta_2$ (iv)	d_4^{25}	ψ_2	N_2	$10^4\delta_D^{25}$	$10^4\delta_2$ (ii)	$10^4\delta_2$ (iv)	d_4^{25}	ψ_2
0·0188	118·3	215·9	217·4	0·7995	153·5	0·1316	151·8	242·1	229·6	0·8736	146·7
0·0475	128·8	224·4	258·0	0·8204	153·3	0·2052	169·9	243·6	244·7	0·9042	156·8
0·0762	136·3	238·1	233·3	0·8387	154·6	0·2068	170·6	246·2	246·2	0·9069	155·9
0·1116	145·9	239·5	239·5	0·8597	155·4	0·2459	177·6	243·9	246·9	0·9237	149·4
							Mean	237·0	239·5		
0·0379	124·6	232·2	232·9	0·8118	154·9	0·1182	147·0	241·7	241·7	0·8753	156·1
0·0705	132·7	228·1	226·6	0·8291	158·3	0·1663	158·8	244·7	244·7	0·8795	156·3
							Mean	236·6	236·6		

Results.—In Table 1, N_2 is the mole-fraction of (−)-ephedrine; δ_D^{25} is the Verdet constant of the solution at 25° and for the Na-*D* line; δ_2 (ii) and δ_2 (iv) are the Verdet constants of (−)-ephedrine calculated respectively according to the volume fraction and the apparent volume fraction rule; d_4^{25} is the density of the solution and ψ_2 is the apparent molar volume of (−)-ephedrine in solution. The first eight solutions were made with (−)-ephedrine hemihydrate and for the purposes of calculation these were assumed to be ternary mixtures of (−)-ephedrine, water, and ethanol. The last four were made with anhydrous (−)-ephedrine and were treated as a binary mixture. An experimental variation of 0·4% in the measurement of the Verdet constant of the solution causes a variation of 2·5% in the derived Verdet constant, δ_2 (ii) and δ_2 (iv).

The Verdet constants of (−)-ephedrine in the ternary system, and in the binary system are listed below, together with the standard errors of the mean.

	10^4 × Verdet constant : for ternary system	for binary system
Volume fraction rule (ii)	237·0 ± 3·7	236·6 ± 3·7
Apparent volume fraction rule (iv)	239·5 ± 4·4	236·6 ± 3·7

In Table 2 is recorded ψ_2, the apparent molar volume of ψ-ephedrine in alcohol, and there is good agreement between the values of the Verdet constant calculated according to either of the above rules.

TABLE 2. *ψ-Ephedrine in ethanol.*

N_2	$10^4\delta_D^{25}$	$10^4\delta_2$ (ii)	$10^4\delta_2$ (iv)	d_4^{25}	ψ_2	N_2	$10^4\delta_D^{25}$	$10^4\delta_2$ (ii)	$10^4\delta_2$ (iv)	d_4^{25}	ψ_2
0·0165	117·2	204·9	204·5	0·7965	157·9	0·0734	133·8	229·6	229·9	0·8317	156·9
0·0276	121·2	220·0	217·0	0·8039	156·6	0·0791	136·3	236·9	236·9	0·8348	157·5
0·0445	126·0	229·6	229·6	0·8415	157·4						
0·0580	129·7	228·5	228·5	0·8228	157·3		Mean	224·8	225·2		
						Standard error of mean		4·0	5·0		

Table 3 gives the various constants for the hydrochlorides of (−)- and ψ-ephedrine in water, and the last table summarises the results.

TABLE 3.

N_2	$10^4\delta_D^{25}$	$10^4\delta_2$ (ii)	$10^4\delta_2$ (iv)	d_4^{25}	ψ_2	N_2	$10^4\delta_D^{25}$	$10^4\delta_2$ (ii)	$10^4\delta_2$ (iv)	d_4^{25}	ψ_2
(a) *(−)-Ephedrine hydrochloride in water.*											
0·0037	135·9	290·7	301·8	1·0035	161·3	0·0150	149·6	282·6	276·0	1·0216	169·1
0·0061	138·9	284·5	289·6	1·0096	164·2	0·0189	154·4	262·7	284·5	1·0264	170·1
0·0084	141·5	278·6	276·0	1·0129	165·8	0·0221	157·0	280·4	281·0	1·0308	169·6
0·0108	144·8	281·5	281·2	1·0149	169·7						
							Mean	283·4	285·6		
						Standard error of mean		2·0	3·0		
(b) *ψ-Ephedrine hydrochloride in water.*											
0·0077	140·8	274·5	274·5	1·0096	171·0	0·0193	154·8	284·4	286·0	1·0266	170·0
0·0127	147·0	278·9	280·8	1·0171	171·5						
							Mean	279·3	280·4		
						Standard error of mean		2·0	3·0		

Summary of the Verdet constants ($\times 10^4$) *and the standard errors of the mean.*

	Volume fraction rule (ii)	Apparent volume fraction rule (iv)
Ephedrine	236·6 ± 3·7	236·6 ± 3·7
ψ-Ephedrine	224·8 ± 4·0	225·2 ± 5·0
Ephedrine hydrochloride	283·4 ± 2·0	285·6 ± 3·0
ψ-Ephedrine hydrochloride	279·3 ± 2·0	280·4 ± 2·0

Discussion.—The higher Verdet constant for (−)-ephedrine suggests that the bonding forces between the molecules of this isomer are less than those between the molecules of ψ-ephedrine. This is in agreement with the differences of melting point, solubility, and volatility of the isomers.

If restricted rotation between the carbon atoms of the propanol side-chain in the ephedrine molecule is accepted, these physical properties would appear to support the configurations suggested by Freudenberg, Schoeffel, and Braun (*J. Amer. Chem. Soc.*, 1932, **54**, 234).

The authors thank Professor Linnell for his interest, Mr. P. C. Barden for constructing the apparatus, and the Central Research Fund of the University of London for a grant towards the cost of equipment.

School of Pharmacy, University of London. [*Received, May 24th*, 1955.]

The Effect of Temperature upon the Equilibrium between Partially Labile Diastereoisomers. Part I. Quinidine Salts in Chloroform Solution.

By Margaret M. Harris.

[Reprint Order No. 6487.]

When quinidine and one molecular proportion of an optically labile acid, *N*-benzoyl-6-methyldiphenylamine-2-carboxylic acid (III; R = Me; R′ = R″ = R‴ = H) are dissolved together in chloroform the solution shows a wide variation of optical rotation with temperature. This has been proved to be due to variation in the position of the equilibrium (+)-Acid,Quinidine ⇄ (−)-Acid,Quinidine with temperature. Several other acids show similar behaviour, in some cases with, and in some without, detectable mutarotation.

The salts formed between an optically labile acid (±)-R·CO_2H and one form of an optically stable base (+)-B are diastereoisomeric and in suitable circumstances will be in equilibrium, (+)-R·CO_2H,(+)-B ⇄ (−)-R·CO_2H,(+)-B. The composition of the equilibrium mixture would be expected to be dependent upon temperature, a dependence which would show itself in a change of optical rotation when the equilibrated solution is viewed successively at different temperatures [Ingram (*J.*, 1950, 2318) reports such a case for the optically stable (+)-camphor-10-sulphonic acid with the optically stable base 10-*m*-aminobenzylideneanthrone].

In the series of substituted *N*-benzoyldiphenylaminecarboxylic acids, suitable members of which are known to be optically active and optically labile (Jamison and Turner, *J.*, 1938, 1646; 1940, 264; Harris, Potter, and Turner, *J.*, 1955, 145), it seems reasonable to assume that salt formation between one molecular proportion of quinidine and one of acid is virtually complete because (*a*) addition of further acid causes a *sharp backward* turn of the curve in which equivalents of acid per equivalent of base are plotted against rotation (*e.g.*, Fig. 1) and (*b*) the freezing-point depression for one mol. of acid and one mol. of base (in this case cinchonidine) dissolved together in the comparable solvent bromoform is equal to that for one mol. of naphthalene (Harris, Potter, and Turner, *loc. cit.*).

The optical rotation of certain single substances, alone or in solution, having only one centre of asymmetry is known to vary with temperature (see, for example, Kauzmann, Walter, and Eyring, *Chem. Rev.*, 1940, **26**, 373) and it would be necessary to be aware of any changes of rotation of this nature before attributing an observed change to shifting of

equilibrium between members of a diastereoisomeric pair. This can be done in three ways. First, the base and an acid which is incapable of optical activity or is optically stable can be taken as a standard of comparison; it should resemble chemically the acid to be investigated as closely as possible: Ingram (*loc. cit.*) used a similar test in an examination of the large change in rotation with temperature of 10-*m*-[(−)-menthoxyacetamido]benzylideneanthrone in chloroform solution; 9-*m*-[(−)-menthoxyacetamido]benzylidenefluorene and (−)-menthoxyacetanilide showed rotations with a much smaller dependence on temperature. Ingram suggested that the large change in rotation was due to the variation in equilibrium composition of the two diastereoisomeric (−)-menthoxyacetyl derivatives of the 10-*m*-aminobenzylideneanthrone: no other manifestation of optical activity could be found, although the structure of the molecule is such that optical activity should be observable if the degree of restriction of rotation is sufficient. 10-*m*-[(−)-Menthoxyacetamido]benzylideneanthrone is particularly interesting in this connection, because the two optically active centres of the diastereoisomers are in chemical combination and not subject to the uncertainties of salt formation. Secondly, if the optical stability permits, the rotation of the partially racemic salt, (±)-R·CO_2H,(+)-B, can be found at various temperatures and compared with the rotations of the equilibrium mixtures. Thirdly, removal of the base

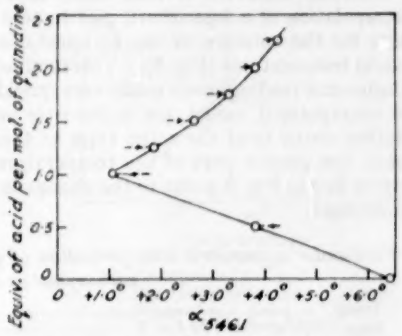


FIG. 1. *Addition of N-benzoyl-6-methyldiphenylamine-2-carboxylic acid to quinidine in chloroform at 20°.*

(The broken lines represent the observed range of mutarotation.)

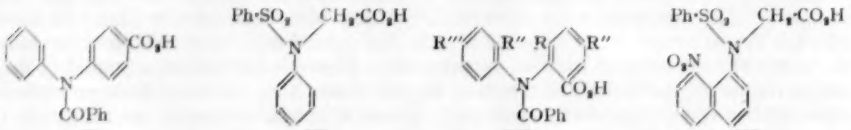
from the mixtures equilibrated at different temperatures should leave specimens of acid which are in varying degrees optically active. All of these methods are exemplified in the present work.

The *N*-benzoyldiphenylaminecarboxylic acids provide excellent material for this investigation because the series includes examples of a large variation in optical stability, from *N*-benzoyldiphenylamine-2-carboxylic acid itself, which is so unstable optically as to show no mutarotation in chloroform in presence of alkaloids even at −33°, to *N*-benzoyl-4′-bromo-2′-chloro-6-methyldiphenylamine-2-carboxylic acid which is sufficiently stable to be isolated in an active form (Harris, Potter, and Turner, *loc. cit.*).

Throughout the present work quinidine has been used as the optically stable, salt-forming base in chloroform solution and the effect of change of temperature upon the equilibrium rotation of its salts with a variety of acids has been ascertained. The concentration of quinidine was constant in all the determinations and equimolecular proportions of the acids were used; the results, which are directly comparable with each other, are plotted in Fig. 2. It will be seen that the acids fall into two main categories, those in which the rotation alters only slightly with temperature and those in which it changes to a substantial degree. The former are the optically inactive acids, benzoic acid, *N*-benzoyldiphenylamine-4-carboxylic acid (I), and *N*-benzenesulphonyl-*N*-phenylglycine (II); the latter are the *N*-benzoyldiphenylamine-2-carboxylic acids (III) and *N*-benzenesulphonyl-8-nitro-1-naphthylglycine (IV) (Mills and Elliott, *J.*, 1928, 1291), all of known low optical stability. *N*-Benzoyldiphenylamine-2-carboxylic acid has never been demonstrated to be optically active by "classical" methods, but its activity is inferred from the effect of excess of the (±)-acid on its cinchonidine and (+)-nor-ψ-ephedrine salts (Jamison and Turner, *loc. cit.*, 1938).

The values of the rotations shown in Fig. 2 are in many cases (*h*, *i*, *j*, *k*, *l*) the final values of observed mutarotations (first-order asymmetric transformations); there is little doubt that the same is true of curves *e*, *f*, and *g* but that the mutarotations are too fast for observation at the temperatures employed. *N*-Benzoyl-6-methyldiphenylamine-2-carboxylic acid (III; R = Me, R′ = R″ = R‴ = H) was selected for more detailed study in this connection.

To a solution of 0·4143 g. of this acid dissolved in 16 c.c. of chloroform at temperature *T*° was added 0·4050 g. (1 mol.) of quinidine. The resulting solution was quickly poured



(I) (II) (III) (IV)

into a polarimeter tube thermostatically controlled at *T*° and readings of α_{5461} were made at recorded intervals of time while first-order asymmetric transformation took place. Extrapolation of a logarithmic plot to zero time (the time of adding the quinidine) gave a value for the rotation of the (±)-acid,quinidine salt. The procedure was repeated at several temperatures (Fig. 3). This method is obviously subject to errors, but as the initial polarimetric readings were made very quickly (within 1—2 minutes of adding the quinidine) the extrapolated values are sufficiently accurate to show that the *initial* temperature–rotation curve is of the same type as the curves for optically inactive acids. In other words, the greater part of the temperature–rotation effect shown in a graph such as the bottom line in Fig. 3 is due to the change in the (+)-acid,quinidine ⇌ (−)-acid,quinidine equilibrium.

First-order asymmetric transformation of quinidine N*-benzoyl-6-methyldiphenylamine-2-carboxylate in chloroform* (Fig. 3).

Temp.		5·2°	16·6°	24·9°	34·6°
α_{5461}:	extrapolated to $t = 0$	+5·70°	+5·86°	+5·97°	+6·2° ± 0·2°
	observed, initial	+5·63	+5·63	+5·21	+5·43
	,, final	+0·45	+1·80	+2·49	+3·41

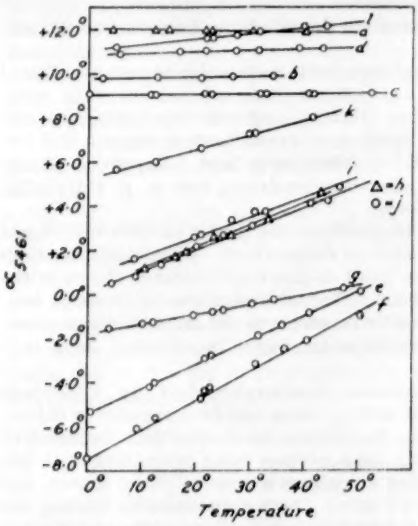
While a solution freshly prepared at 20·2° of the (±)-acid (0·4143 g.) and quinidine (0·4050 g.) in 16 c.c. of chloroform showed mutarotation from $\alpha_{5461} = +3·68°$ after 13 minutes to +2·21° after 2 hours, one of the same composition which was left overnight at 3·5° and then quickly warmed to 21° changed in rotation from +0·56° to +2·23° in the same time (Fig. 4).

N-Benzoyl-6-methyldiphenylamine-2-carboxylic acid although previously described (Turner and his co-workers, *locc. cit.*, 1940, 1955) had not been obtained optically active. During the present work it was found possible to obtain it in the lævorotatory form, in varying degrees of optical purity, in chloroform solution. When three of the equilibrated solutions represented by curve (*j*) (Fig. 2) were decomposed by ice-cold hydrochloric acid, specimens of active acid were obtained which racemised rapidly in chloroform at 21° (Fig. 5).

Lesslie, Turner, and Winton (*J.*, 1941, 257) observed a large variation with temperature in the rotation of quinine diphenate in ethanol–chloroform solution. It seems probable that they were observing a shifting equilibrium here, analogous to those recorded in Fig. 2.

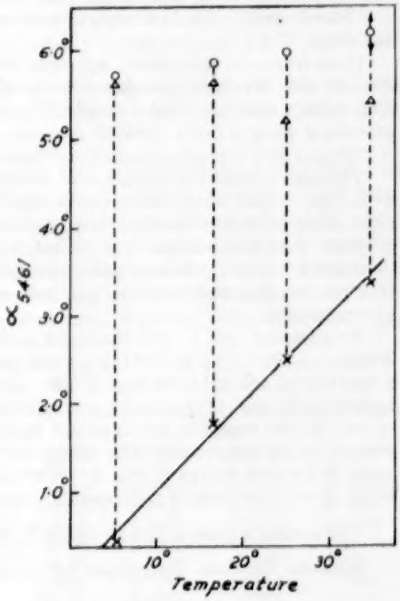
Although the temperature–rotation work now reported has all been carried out with quinidine as the optically active agent, preliminary experiments show that cinchonidine and cinchonine behave to a certain extent similarly and they are being investigated further. If the phenomenon is general and is capable of being distinguished from other temperature-dependent influences on rotation, it should be of value in the diagnosis of optical activity in highly labile compounds. It may also be noted that this temperature-dependent equilibrium could be an important factor in some asymmetric syntheses which proceed by way of optically labile diastereoisomeric transition states.

FIG. 2. *Rotation of quinidine salts in chloroform.*



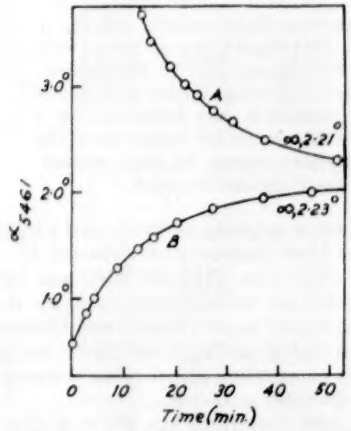
(*a*) *Quinidine alone.*
(*b*) *Benzoic acid.*
(*c*) (I).
(*d*) (II).
(*e*) (III; R = R′ = R″ = R‴ = H).
(*f*) (III; R = R′ = H, R″ = R‴ = Cl).
(*g*) (III; R = R′ = H, R″ = R‴ = Me).
(*h*) (III; R = R′ = Cl, R″ = R‴ = H).
(*i*) (III; R = R′ = Br, R″ = R‴ = H).
(*j*) (III; R = Me, R′ = R″ = R‴ = H).
(*k*) (III; R = Me, R′ = H, R″ = R‴ = Cl).
(*l*) (IV).

FIG. 3. *First-order asymmetric transformation of N-benzoyl-6-methyldiphenylamine-2-carboxylic acid with quinidine in chloroform at various temperatures.*



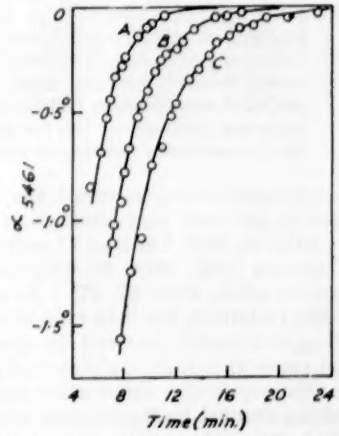
○ *Extrapolated to t = 0.*
× *Observed final point.*
△ *Observed first point.*

FIG. 4. *N-Benzoyl-6-methyldiphenylamine-2-carboxylic acid with quinidine in chloroform.*



A, First-order asymmetric transformation at 20·2°.
B, Equilibration at 21° of a solution which had been allowed to stand at 3·5°.

FIG. 5. *Racemisation of (−)-N-benzoyl-6-methyldiphenylamine-2-carboxylic acid in chloroform at 21°.*



From asymmetric transformation at (A) 45°, (B) 21°, (C) 0·8°.

Experimental

The diphenylaminecarboxylic acids were prepared as described by Jamison and Turner, and by Harris, Potter, and Turner (*locc. cit.*).

Chloroform for rotation experiments was washed repeatedly with water to remove ethanol and dried.

Quinidine.—A chloroform solution of quinidine (Harringtons) was dried (Na_2SO_4) and filtered, and dry light petroleum (b. p. 40—60°) added until crystallisation began: the first crop, which was oily, was filtered off quickly and the second crop kept. Repetition of this procedure gave a finely divided specimen which after vacuum-drying had m. p. 171°, $[\alpha]_{5461}^{21\cdot5}$ +236° (*c*, 2·531 in freshly washed and dried chloroform).

The measurement of variation of rotation with temperature was carried out in a well-lagged 2-dm. tube round which water was pumped at the required temperature. Polarimetric readings were made at steady temperatures, mounting from point to point up the range shown in the graphs; then the solution was cooled, readings being taken at descending intervals of temperature down to the lowest point recorded, and finally returning to the original temperature: this procedure guards against any irreversible change which might be mistaken for a shift of equilibrium.

Preparation of (−)-N-Benzoyl-6-methyldiphenylamine-2-carboxylic Acid in Chloroform Solution.—The (±)-acid (0·4143 g.) and quinidine (0·4050 g.) were dissolved together in chloroform (16 c.c.) and left for 2 days at 0·8°; at $t = 0$ min. the solution was washed with concentrated hydrochloric acid to which ice was added, with the same mixture twice again, then with ice-water; it was then run into a cooled flask containing anhydrous sodium sulphate, shaken, and filtered into a polarimeter tube (temp. 21°) at $t = 5{\cdot}5$ min. The first polarimetric reading was made at 7·8 min. (curve *C*, Fig. 5). Curves *A* and *B* were obtained similarly, with the difference that the solutions before decomposition were left at 45° and 21° respectively.

The author is indebted to Professor E. E. Turner for his interest in this work.

Bedford College, University of London. [*Received, June 7th*, 1955.]

Activity Coefficients of Sulphuric Acid in Aqueous Propylene Glycol and Aqueous Propan-1-ol at 25°.

By C. M. French and Ch. F. Hussain.

[Reprint Order No. 6517.]

Electromotive force measurements have been made on the cell H_2 (1 atm.)|H_2SO_4(m), alcohol (*x*%), H_2O (100 − *x*%)|Hg_2SO_4–Hg at 25° c, with propan-1-ol and also propylene glycol as the organic part of the solvent. Values of *x* of 5, 10, and 20 were used, and the acid concentration (molal) was varied between 0·05 and 1·00. Standard potentials were computed by a graphical extrapolation method and are plotted against the reciprocal of the dielectric constant of the solvent giving smooth curves for each alcohol. Mean ion-activity coefficients were also calculated and are recorded.

The electromotive force between a mercury–mercurous sulphate electrode and a hydrogen electrode in sulphuric acid solutions in water has been measured by Brønsted (*Z. phys. Chem.*, 1910, **68**, 693), Lewis and Lacey (*J. Amer. Chem. Soc.*, 1914, **36**, 804), and Randall and Cushman (*ibid.*, 1918, **40**, 393), and the results are critically surveyed by Harned and Hamer (*ibid.*, 1935, **57**, 27). As noted in an earlier paper (French and Hussain, *J.*, 1955, 2211) relatively few data exist for solutions in organic and aqueous-organic media. It was thought desirable to extend the measurements on ethylene glycol systems reported in the last paper to propylene glycol– and propan-1-ol–water mixtures.

In this way further information may be obtained concerning the effect of change of solvent, as denoted by its dielectric constant, on the mean-ion activity coefficient of the solute.

Experimental.—Electromotive forces were measured with the apparatus described earlier (French and Hussain, *loc. cit.*) and were reproducible to within ±0·05 mv. The cells containing the solutions under investigation were kept in an air thermostat at 25° ± 0·02° during measurement.

Propylene glycol was purified by the method of Smyth and Walls (*J. Amer. Chem. Soc.*, 1931, **53**, 2116), and was finally distilled at 4 mm.; it had b. p. 62°/4 mm., d_4^{25} 1·0327, n_D^{25} 1·4315 (lit., d_4^{25} 1·0328, n_D^{25} 1·43143).

Propan-1-ol, purified according to Lund and Bjerrum's directions (*Ber.*, 1931, **64**, 210) and finally fractionated, had d_4^{25} 0·7996, n_D^{25} 1·3835 (lit., d_4^{25} 0·7993, 0·7999, 0·79985; n_D^{25} 1·3833, 1·3834).

Results and Discussion.—In all cases equilibrium was slowly attained and this was particularly marked in the case of 20% propylene glycol where constant values were obtained only after 30 hr. The mean e.m.f. of three solutions measured concurrently and agreeing generally to within 0·05 mv was taken as that of the solution under investigation. All these results were corrected to 1 atm., by using the measured vapour pressure of the corresponding sulphuric acid solutions. The resulting e.m.f. values are given in the Table (where d is the density and ε the dielectric constant) together with the mean ion-activity coefficients ($\gamma_\pm$).

Molality	d_4^{25}	E.m.f.	$\lambda_\pm$	$\lambda_\pm'$	d_4^{25}	E.m.f.	$\lambda_\pm$	$\lambda_\pm'$
	10% Propan-1-ol ($E°$ 0·6065), vap. press. 30·71 mm.				20% Propan-1-ol ($E°$ 0·6011), vap. press. 34·19 mm.			
0·05	0·9879	0·7473	0·3261	0·4087	0·9715	0·7425	0·3210	0·4629
0·1	0·9909	0·7305	0·2522	0·3161	0·9745	0·7260	0·2463	0·3552
0·2	0·9969	0·7136	0·1955	0·2451	0·9804	0·7092	0·1905	0·2747
0·3	1·0028	0·7037	0·1686	0·2112	0·9862	0·6991	0·1651	0·2380
0·4	1·0087	0·6962	0·1536	0·1924	0·9922	0·6916	0·1504	0·2168
0·5	1·0147	0·6901	0·1439	0·1803	0·9979	0·6857	0·1403	0·2021
0·6	1·0207	0·6853	0·1358	0·1702	1·0038	0·6810	0·1320	0·1903
0·7	1·0266	0·6809	0·1305	0·1636	1·0097	0·6761	0·1284	0·1852
0·8	1·0326	0·6770	0·1264	0·1584	1·0157	0·6724	0·1238	0·1784
0·9	1·0386	0·6734	0·1233	0·1546	1·0217	0·6689	0·1205	0·1738
1·0	1·0445	0·6703	0·1203	0·1508	1·0276	0·6659	0·1172	0·1690
	5% Propylene glycol ($E°$ 0·6092), vap. press. 23·4 mm.				10% Propylene glycol ($E°$ 0·6068), vap. press. 23·00 mm.			
	ε_{25} = 76·9				ε_{25} = 74·8			
0·05	1·0074	0·7502	0·3244	0·3791	1·0107	0·7483	0·3203	0·3983
0·1	1·0103	0·7338	0·2483	0·2901	1·0137	0·7318	0·2458	0·3056
0·2	1·0162	0·7168	0·1831	0·2255	1·0198	0·7153	0·1886	0·2345
0·3	1·0221	0·7065	0·1681	0·1964	1·0257	0·7050	0·1643	0·2042
0·4	1·0281	0·6992	0·1523	0·1780	1·0316	0·6977	0·1488	0·1851
0·5	1·0340	0·6933	0·1420	0·1660	1·0375	0·6918	0·1388	0·1726
0·6	1·0399	0·6882	0·1351	0·1579	1·0434	0·6867	0·1320	0·1642
0·7	1·0457	0·6837	0·1301	0·1522	1·0494	0·6825	0·1262	0·1570
0·8	1·0516	0·6799	0·1257	0·1469	1·0550	0·6787	0·1219	0·1516
0·9	1·0574	0·6763	0·1228	0·1432	1·0607	0·6751	0·1190	0·1479
1·0	1·0634	0·6733	0·1193	0·1395	1·0665	0·6722	0·1154	0·1435
	20% Propylene glycol ($E°$ 0·6013), vap. press. 22·21 mm.							
	ε_{25} = 71·1							
0·05	1·0193	0·7430	0·3185	0·4569				
0·1	1·0223	0·7267	0·2432	0·9488				
0·2	1·0283	0·7101	0·1871	0·2683				
0·3	1·0340	0·6998	0·1629	0·2337				
0·4	1·0399	0·6923	0·1485	0·2129				
0·5	1·0457	0·6865	0·1380	0·1980				
0·6	1·0514	0·6819	0·1296	0·1859				
0·7	1·0572	0·6775	0·1246	0·1786				
0·8	1·0630	0·6740	0·1193	0·1712				
0·9	1·0689	0·6703	0·1168	0·1675				
1·0	1·0747	0·6673	0·1136	0·1629				

The value of the standard potential (shown in the Table) for each solvent medium was computed by Land and Crockford's method (*J. Amer. Chem. Soc.*, 1950, **72**, 1895), as

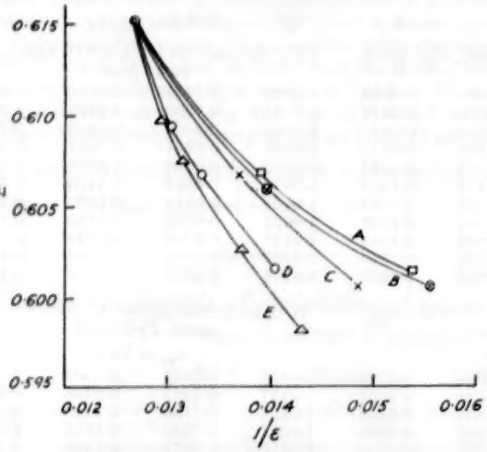
described by French and Hussain (*loc. cit.*). As in the case of ethylene glycol the plots of ΔE against $m^{\frac{1}{2}}$ were linear for concentrations greater than 0·16m. At lower concentrations smooth curves closely resembling those of ethylene glycol and with a similar curvature were obtained. Graphical extrapolation to zero acid concentration was therefore effected as before.

The activity coefficients were calculated from the equation

$$E = E_0 - \frac{3RT}{2F} \ln (4^{\frac{1}{2}} m\gamma_{\pm})$$

Again the activity coefficients γ were calculated on the basis of a reference state of unit activity coefficient for the acid at infinite dilution in the given solvent. The activity coefficients γ' were calculated on the basis of a reference state of unit activity coefficient for the solute at infinite dilution in pure water. For this purpose the value of E° obtained by Harned and Hamer (*loc. cit.*) was employed.

Curves obtained by plotting γ and γ' against $m^{\frac{1}{2}}$ fall respectively below and above the same curves for systems in pure water, but resemble them closely and show the same tendency towards a minimum in each medium.



A, Propan-1-ol–water.
B, Propan-2-ol–water.
C, Ethanol–water.
D, Propylene glycol–water.
E, Ethylene glycol–water.

Finally it may be noted that if E° for each solvent medium is plotted against the reciprocal of the dielectric constant of that solvent, then a smooth curve is obtained for each aqueous organic medium. All curves have, of course, a common origin at the E° value for pure water. The curves for the systems investigated by the present authors together with those for ethanol and propan-2-ol obtained by Crockford and Wideman (*J. Phys. Chem.*, **1946**, **50**, 418) and Land and Crockford (*loc. cit.*) are shown in the Figure. It will be observed that the curves for the monohydric alcohols are close together, particularly for the isomeric propanols, and are distinct from the curves for the dihydric alcohols.

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Steric Interactions in Substituted cyclo*Hexadienes. Part I.* meso-*Substituted Dihydroanthracenes: Steric Effects in the Reactions of* cis- *and* trans-*Isomers.*

By A. H. Beckett and B. A. Mulley.

[Reprint Order No. 6133.]

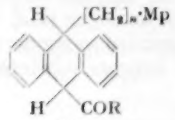
Stereoisomeric pairs of *meso*-substituted 9 : 10-dihydroanthracenes are prepared and their configurations elucidated. The interconversions and the differences in reactions and reactivities of the *cis*- and the *trans*-isomers are investigated.

The dihydroanthracenes are considered as substituted *cyclo*hexa-1 : 4-dienes; conformational analysis is made, generalisations are formulated, and differences in properties of stereoisomers are explained in terms of conformations.

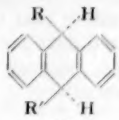
In an investigation of the stereochemical requirements of analgesics (cf., *e.g.*, Beckett and Casy, *J. Pharm. Pharmacol.*, **1954**, **6**, 986), a few geometrically isomeric pairs of dihydroanthracenes (I) were required carrying aminoalkyl and acyl (or ester) *meso*-substituents.

However, a wider interest was also involved. Dihydroanthracenes represent the parent structures of a type of compound which may be regarded as *cyclo*hexane-1 : 4-dienes existing in a " flattened boat " conformation with flat planar rings fused to its sides. The various probable geometrical arrangements of *meso*-groups relative to the planar rings in systems of this type raise interesting possibilities.

Isomeric 9 : 10-*Disubstituted* 9 : 10-*Dihydroanthracenes.*—The *cis*-diacid (II*a*) was obtained by acid hydrolysis of the *cis*-monoester (II*b*). Alkaline hydrolysis of the anhydride of the acid yielded the *trans*-diacid (III*a*). The configurations of these two isomers have been established by Mathieu [*Ann. Chim.* (*France*), **1945**, **20**, 215] who showed that the *cis*-acid (II*a*) formed the anhydride readily with acetic anhydride whereas the *trans*-isomer (III*a*) more slowly gave the same anhydride.

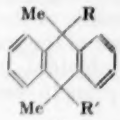


(I)

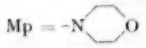


(II)

(III)



(IV)

Mp = 

	R	R′	R	R′
(*a*)	CO_2H	CO_2H	(*f*) CH_2·OAc	CH_2Mp
(*b*)	CO_2H	CO_2Me	(*g*) CH_2·OH	COMp
(*c*)	CO_2Me	COMp	(*h*) COEt	COMp
(*d*)	CO_2H	COMp	(*i*) CHEt·OH	CH_2Mp
(*e*)	CH_2·OH	CH_2Mp	(*j*) CHEt·OH	COMp

The *cis*-morpholide-ester (II*c*) was prepared by treating 9 : 10-dihydroanthracene-9 : 10-dicarboxylic anhydride (Beckett, Lingard, and Mulley, *J.*, 1953, 3328) with methyl alcohol to give the monoester (II*b*) and converting this into the acid chloride which was condensed with morpholine. The *trans*-isomer (III*c*) was obtained by converting the anhydride by morpholine into the morpholide-acid (III*d*) and esterifying this. The allocation of these configurations, and those of the intermediate compounds, rests upon the following observations.

(1) Ring opening of the anhydride with methyl alcohol would be expected to yield a *cis*-monoester, and hydrolysis of this ester yields the *cis*-diacid. [Separate experiments showed that the *trans*-diacid (III*a*) is not isomerised to the *cis*-diacid (II*a*) on comparable treatment, whereas the *cis*-diacid is *slowly* converted into *trans*-diacid on prolonged heating

with concentrated hydrochloric acid. The *cis*-diacid is rapidly isomerised by alkali to the *trans*-diacid. Consequently the results of acid, but not of alkaline, hydrolysis provide evidence of configuration. However, other supporting evidence is usually required because certain *trans*-isomers, other than diacids, are converted into *cis*-isomers by boiling concentrated hydrochloric acid (see below).]

(2) The above-mentioned morpholide-acid (III*d*) is isomeric with the *cis*-isomer (II*d*) obtained by acid hydrolysis of the *cis*-morpholide-ester (II*c*). The *trans*-morpholide-acid (III*d*) was inverted to this *cis*-isomer (II*d*) by boiling concentrated hydrochloric acid, a small amount of *trans*-diacid (III*a*) being also isolated.

(3) Treatment of the *trans*-morpholide-acid (III*d*) with diazomethane, which will give the corresponding methyl ester with retention of configuration, gave a product (III*c*) which was isomeric with the morpholide-ester obtained by treating the *cis*-monoester (II*b*) with thionyl chloride followed by morpholine. Esterification of the *trans*-morpholide-acid (III*d*) by the Fischer–Speier method yielded a mixture of the *cis*- and *trans*-esters (II*c* + III*c*), the latter predominating. The fact that alkaline hydrolysis of either of these morpholide-esters, or treatment of the *cis*-morpholide-acid with alkali, yields products which are identical with the morpholide-acid obtained by ring opening of the anhydride with morpholine provides further support for our allocation of configurations to these acids.

(4) 9 : 10-Dimethyl-9 : 10-dihydroanthracene-9 : 10-dicarboxylic anhydride, on treatment with methyl alcohol and with morpholine, yielded the acid-ester (IV*b*) and the morpholide-acid (IV*d*) respectively, both of the *cis*-configuration since epimerisation cannot occur. [The dimethyl anhydride yielded a *cis*-diacid (IV*a*) on hydrolysis with alkali and the morpholide-acid (IV*d*) was not inverted by alkali. Preliminary work had resulted in the isolation of isomeric diacids from the mixtures obtained by carbonating the sodio-derivative of 9 : 10-dimethylanthracene, and only one of these, to which the *cis*-configuration was allocated, was converted into an internal anhydride by hot acetic anhydride.] The *cis*-morpholide ester (IV*c*) was obtained stereochemically pure from *cis*-morpholide-acid by means of diazomethane or by the reaction of the *cis*-monoester (IV*b*) with thionyl chloride followed by morpholine. The amido- and ester-carbonyl stretching frequencies (see Table 1) of the *cis*-morpholide-ester (IV*c*) are identical with those of the non-methylated analogue (II*c*) to which, on chemical evidence, the *cis*-configuration had been assigned, but not with those of its stereoisomer; also the carbonyl frequencies of the *cis*-morpholide-acid (IV*d*) resembles that of the *cis*-analogue (II*d*) but not that of the *trans*-analogue (III*d*). (The infrared data are only regarded as supporting those obtained by the chemical interconversions, because of the dangers inherent in attempting to correlate infrared spectra obtained on solids.)

TABLE 1. *Carbonyl stretching frequencies of* meso-*substituted* 9 : 10-*dihydroanthracenes.*

	Subst.*		C=O stretching (cm.$^{-1}$) *cis*	*trans*	Band allocation
c	H ... COMp		1740	1734	Ester
	H ... CO_2Me		1637	1650	Amide
c	Me ... COMp		1740	—	Ester
	Me ... CO_2Me		1637	—	Amide
d	H ... COMp		1734	1722	Acid
	H ... CO_2H		1598	1593	Amide †
d	Me ... COMp		1731	—	Acid
	Me ... CO_2H		1598 (1608)	—	Amide †
a	H ... CO_2H		1708 (1645)	1697	Acid
	H ... CO_2H				

* Mp = morpholide residue. † Bonded.

The *cis*-amido-ester (II*c*) was reduced readily and almost quantitatively by lithium aluminium hydride to an amino-alcohol (II*e*) which has the *cis*-configuration since such reductions proceed with retention of configuration (Noyce and Denney, *J. Amer. Chem. Soc.*, **1950**, **72**, **5743**). With acetic anhydride this alcohol readily gave the acetate (II*f*). On the other hand, the *trans*-amido-ester (III*c*) gave only small amounts of *trans*-amino-alcohol, the main product being the *trans*-amido-alcohol (III*g*); and the *trans*-amino-alcohol was esterified only with difficulty.

A mixture of isomeric morpholino-ketones was obtained on treatment of the *trans*-morpholide-acid (III*d*) with thionyl chloride followed by diethylcadmium. One ketone

(A) was not inverted by acid, gave a stereochemically pure 2 : 4-dinitrophenylhydrazone under acid conditions, and was readily reduced with lithium aluminium hydride to an amino-alcohol which could be readily esterified with acetyl chloride. The other ketone (B) was partially inverted to ketone (A) by hot acid, gave a mixture of 2 : 4-dinitrodiphenylhydrazones (one identical with the product from ketone A), and was reduced, with great difficulty, mainly to an amido-alcohol. Therefore, by analogy, amido-ketone A and its derivatives are assigned the *cis*-configuration, and the B series the *trans*-configuration.

Some anomalies in melting points in these series require mention. The *cis*-diacid (II*a*) has been reported to melt at 294° (Schlenk and Bergmann, *Annalen*, 1928, **463**, 134) and 283° (block) (Mathieu, *loc. cit.*); our product, when placed in the heating block 10° below the melting point, partially melted at 265—266°, rapidly solidified, and then remelted at 301—302°. This is due to isomerisation; the *cis*- isomerised completely to the *trans*-isomer (identity confirmed by solubility and infrared absorption) when heated from 260° to 285° in 1 minute. Further, certain *trans*-derivatives can isomerise to *cis*-isomers when heated (see below), and decarboxylation has been found to occur with certain *meso*-dihydroanthracene acids (see Mathieu, *loc. cit.*); but, in our experience, reproducible melting points can be obtained if the compounds are placed in the heating block just below their melting points and the temperature raised at about 10° per minute. It is worthy of note that in this series, if the 9- and the 10-substituents are identical, the *trans*- have higher melting points than the *cis*-isomers, whereas the reverse is the case when the two substituents are not identical. The melting points of many pairs of isomers described in the literature follow the same rule (cf., *e.g.*, Mathieu, *loc. cit.*; Rigaudy, *Ann. Chim.* (*France*), 1950, **5**, 398).

In Table 2, certain inversions are summarised. Precise measurements have not yet been carried out, but infrared spectra, melting points, and solubilities indicate that the equilibria lie in the direction indicated in the Table. It is apparent that, in general, if an isomer is inverted by alkali, the *cis*-configuration can be assigned, whereas the *trans*-configuration can be assigned to an isomer which is inverted by acid. Rigaudy (*loc. cit.*) has observed similar interconversions in certain 9 : 10-diketones and keto-acids of 9 : 10-dihydroanthracene. The significance of the terms "*cis*" and "*trans*" will be considered below.

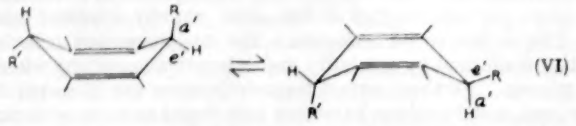
TABLE 2. *Inversions of* cis- *and* trans-*isomers of* 9 : 10-*disubstituted* 9 : 10-*dihydroanthracenes.*

9 : 10-Substituents [a]		*cis*	*trans*
CO_2H	CO_2H [a]	Aq. alkali → *trans* Acid → *trans* Heat → *trans*	Unchanged by heat alone or with acid or alkali
CO_2H	COMp [a]	Aq. alkali → *trans* Unchanged by heat alone or with acid	Heat → *cis* Acid → *cis*
CO_2Me	COMp [a]	Aq. alkali → *trans*-amido-acid Acid → *cis*-amido-acid	Aq. alkali → *trans*-amido-acid
COEt	COMp [a]	Unchanged by heat alone or with acid	Acid → *cis*
CO_2Me	CO_2Me [b]	—	Heat → *cis*
$CO{\cdot}C_6H_4Me$	$CO{\cdot}C_6H_4Me$ [c]	KOMe → *trans*	Acid → *cis*
CO_2H	$CO{\cdot}C_6H_4Me$ [c]	Aq. alkali → *trans*	Acid → *cis* Heat → *cis*
CO_2H	$CO{\cdot}C_6H_4{\cdot}OMe$ [d]	Aq. alkali → *trans*	—
$CO{\cdot}C_6H_4{\cdot}OMe$	$CO{\cdot}C_6H_4{\cdot}OMe$ [d]	KOMe → *trans*	—

[a] Present work. [b] Mathieu, *loc. cit.* [c] Rigaudy, *loc. cit.* [d] Rigaudy and Farthouat, *Compt. rend.*, 1952, **234**, 1064.
[a] Mp = morpholide residue.

Conformational Considerations.—The conformation of the central ring of 9 : 10-dihydroanthracene and its *meso*-substituents has been described in a preliminary communication (Beckett and Mulley, *Chem. and Ind.*, 1955, 146). In the 9 : 10-positions two geometrically

distinct types of bonds, now designated quasiequatorial (e') and quasiaxial (a'),* are present. The shallow boat conformation of the central ring (V) may be converted into conformation (VI) by " reverse folding " about the 9 : 10-axis, with the consequent interconversion of a' and e' bonds. Quasiequatorial groups are subjected to greater non-bonded interactions than the corresponding quasiaxial groups in this system. The preferred conformation of a 9 : 10-disubstituted dihydroanthracene will therefore be that which results in the quasiaxial form for the more bulky groups if there is no strong electrostatic repulsion between the two substituents, *e.g.*, a *trans*-dialkyl compound will have the conformation (VI) rather than (V) if R' is larger than R.

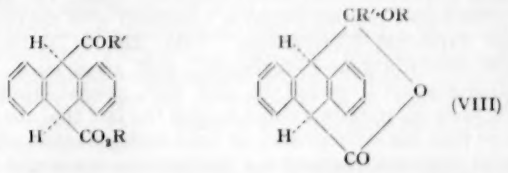


It has been shown (*e.g.*, by Barton and Schmeidler, *J.*, 1948, 1197; Corey, *J. Amer. Chem. Soc.*, 1953, **75**, 2301) that strong electrostatic effects in *cyclo*hexane systems may result in exceptions to the generalisation that the thermodynamically most stable conformation is the one involving a minimum of non-bonded interactions. Consequently, when each *meso*-position of 9 : 10-dihydroanthracene is monosubstituted by groups such as RCO or CO_2H which can exert strong repulsive forces upon each other, especially under alkaline conditions, the allocation of " *cis* "- and " *trans* "-configurations to the pairs of isomers which have been obtained requires further consideration because the distance between the two substituents is in the order e'e' (*cis*) > e'a' (*trans*) > a'a' (*cis*). If isomer A is stable to alkali and isomer B is isomerised to A by treatment with alkali (or if isomer A is present in larger amounts than B in the equilibrated mixture), three possible allocations of configurations must be considered, *viz.*, (1) A as " *trans* " (e'a') with B " *cis* " (a'a'), (2) A as " *cis* " (e'e') with B " *trans* " (e'a'), and (3) A as " *cis* " (e'e') with B " *cis* " (a'a'). The last of these possible allocations can readily be rejected: for the strained " planar " dihydroanthracene conformation constitutes only a low energy barrier between the two forms of which one would be subject to considerable non-bonded interactions, and further, the inversion of B to A with alkali involves epimerisation, and only two isomers have been isolated from such systems whereas the allocation would require three isomers, namely, e'e', a'a', and e'a'. The second possibility allows of maximum group separation in the e'e' conformation, but, in such a conformation, both groups will be subject to considerable non-bonded interactions from the flanking aromatic ring substituents, whereas the first possibility will result in strong electrostatic repulsion between the groups but non-bonded interactions will be reduced to the minimum; the result is therefore mainly dependent upon the relative importance of the non-bonded interactions compared with the electrostatic repulsions. That the allocations should be made according to the first rather than the second possibility is indicated from the following observations: the 9 : 10-dihydroanthracene-9 : 10-dicarboxylic acid isomer which is isomerised with alkali (isomer B) is readily converted into the internal anhydride, whereas isomer A forms the *same* anhydride but only on more vigorous treatment, indicating that isomer B is unlikely to have the e'a' conformation; an approximate vectorial summation of moments indicates that the ratio of dipole moments of the A type [obtained from the diacid stable to alkali by Mathieu (*loc. cit.*)] to the B type (obtained from diacid which epimerises with alkali) isomers of dimethyl 9 : 10-dihydroanthracene-9 : 10-dicarboxylate will be approximately 0·7 if the A type is e'a' and the B type is a'a' but virtually zero if isomer A is e'e' and

* Quasiequatorial and quasiaxial orientations were designated *lin* and *perp* in our previous communication for reasons there stated. The Referees consider the former terms to be preferable because the geometrical arrangement of the bonds at the " ends " of a 1 : 4-*cyclo*hexadiene boat may be related to the orientations of the bonds of *cyclo*hexane chairs (Barton, Hassel, Pitzer, and Prelog, *Nature*, 1953, **172**, 1096) and *cyclo*hexene " half chairs " (Barton, Cookson, Klyne, and Shoppee, *Chem. and Ind.*, 1954, 21). The relative compressions of the groups in these 1 : 4-*cyclo*hexadienes are consequently the reverse of those which obtain in the similarly designated groups in the *cyclo*hexenes.

B is e'a'—reported values (Bergman and Weizmann, *J. Amer. Chem. Soc.*, 1938, **60**, 1801) for the dipole moments of the two isomers give a ratio of approx. 0·65. "*trans*"-Isomers may therefore be regarded as existing in the e'a' and "*cis*"-isomers in the a'a' conformations.

There is a possibility that the interconversion of certain *trans*- and *cis*-isomers [*e.g.*, (VII); R = H or Me, R' = morpholino, etc.] when heated alone or in the presence of acid might be partly attributed to the existence of the latter as cyclic structures (VIII) in addition to the stabilisation effected by the reduction of non-bonded interactions. Similar



cyclisations have been reported, *e.g.*, 8-benzoyl-1-naphthoic acid has been isolated in a "cyclic" and an "open" form (French and Kircher, *J. Amer. Chem. Soc.*, 1944, **66**, 298). Grove and Willis (*J.*, 1951, 877) showed that in δ- and γ-aldehydo- and -keto-acids the "open" form will have two C=O absorption bands in the C=O stretching region, whereas the cyclic forms will only exhibit one lactone C=O absorption. The presence of two carbonyl infrared bands (Table 1, first and third compound) for both *cis*- and *trans*-disubstituted 9 : 10-dihydroanthracenes indicates that the cyclic structure (VIII) does not contribute to the stability of the *cis*-isomer.

Consideration of molecular models indicates that bimolecular reactions involving an atom or group in the e' conformation will proceed only with great difficulty, although the possibility of "reverse folding" of the dihydroanthracene structure to convert an e' into an a' substituent will be possible, *e.g.*, when the a' group is more bulky than the e' group, bimolecular reaction involving the latter will necessitate "reverse folding" and reversed conformation; this change will constitute a considerable energy barrier to the reaction, since the group originally a' will have to be forced into a position of considerable non-bonded interactions and steric constraints.

The observed differences in the reactions and reactivities of certain *cis*- and *trans*-disubstituted 9 : 10-dihydroanthracenes can be explained in terms of the preferred conformations of the isomers.

The almost quantitative reduction of the *cis*-morpholide-ester (II*c*) into the *cis*-amino-alcohol (II*e*) by lithium aluminium hydride, in contrast to the reduction of the *trans*-isomer (III*c*) to yield only 10% of the *trans*-amino-alcohol and about 80% of the *trans*-amido-alcohol (III*g*) is explicable since the ester group, being more readily attacked by the reagent than the amido-group, will probably be attacked only when it is in the a' position, and the resulting bulky reduced complex causes the amido-group in the *trans*-isomer to remain in the hindered e' position where it is almost completely shielded; both ester and amido-group can be readily attacked in the *cis*-isomer in which they are both in the a' position. The fact that the *cis*-morpholide-ketone (II*h*) gives quantitative yields of the *cis*-amino-alcohol (II*i*) whereas the corresponding *trans*-ketone is reduced only with great difficulty to give poor yields of *trans*-amino-alcohol and large yields of *trans*-amido-alcohol (III*g*) can be accounted for similarly.

The following striking contrasts in the reactions of certain isomeric pairs of compounds can also be explained in terms of a hindered e' position for one substituent in the *trans*-isomer: the *trans*-amino-alcohol (III*e*) cannot be esterified under conditions which are successful for its *cis*-isomer; 9 : 10-dihydroanthracene-9 : 10-*trans*-dicarboxylic acid requires treatment with thionyl chloride for 5—20 hours to produce the *trans*-diacid chloride, whereas 15 minutes suffice for the *cis*-diacid (Mathieu, *loc. cit.*); *trans*-9 : 10-diacyl-9 : 10-dihydro-acids yield their acid chlorides with great difficulty and unchanged acids are always present, whereas the *cis*-isomers yield acid chlorides readily (Rigaudy,

loc. cit.); the 9 : 10-*cis*-diacid chloride reacts at room temperature with anisole in the presence of aluminium chloride to give a diketone, whereas the *trans*-diacid chloride requires heating at 80° (Rigaudy, *loc. cit.*).

It has been reported that *cis*-9 : 10-dihydro-9 : 10-dimethylanthracene is stable to aluminium chloride in benzene for 2 hours while the *trans*-isomer is dehydrogenated under similar conditions (Badger, Jones, and Pearce, *J.*, 1950, 1700). In the former, both *meso*-hydrogen atoms will be in e′ positions whereas in the *trans*-isomer one hydrogen atom will be a′ and thus susceptible to attack. (The assignment of the configurations was not rigidly established but, since both *meso*-groups are equal, the assignment of the *trans*-configuration to the higher-melting isomer is consistent with the empirical rule on p. 4161).

Rigaudy and Farthouat (*Compt. rend.*, 1953, **236**, 1173) have reported that *cis*-9-benzoyl-9 : 10-dihydroanthracene-10-carboxylic acid gives *cis*-9 : 10-dihydro-9-(hydroxydiphenylmethyl)anthracene-10-carboxylic acid with phenyl-lithium, whereas the *trans*-isomer yields the same *cis*-tertiary alcohol despite the fact that the *trans*- is thermodynamically more stable than the *cis*-acyl-acid, at least under alkaline conditions. Presumably, in the *trans*-isomer, the benzoyl group is e′ and requires conversion into an a′ conformation before reaction with the group can occur, and less energy is involved in the interconversion of *trans*- into the *cis*(*i.e.*, a′a′)-configuration than would be involved in forcing the bulky carboxylate ion into the e′ conformation.

The interconversions of the 9 : 10-disubstituted 9 : 10-dihydroanthracenes recorded in Table 2 can be explained in terms of the differences in the combined electrostatic and non-bonded flanking atom interactions obtaining in the a′a′ and e′a′ conformations. At least one group is present in these compounds to allow of incipient enolisation of a *meso*-hydrogen atom by which inversion can be realised. The inversion of the *trans*-amido-acid (Table 2, second compound) and the *trans*-diketone (Table 2, sixth compound) upon heating indicates that stabilisation of the molecule by reduction of non-bonded interactions is effected by the change of one e′ (*trans*-isomer) to an a′ group (*cis*-isomer), the other a′ group being unchanged, despite the resultant increase in electrostatic repulsions between the groups. However, when the *cis*-isomers are heated in alkali, the acidic group is present as an anion, and the partial negative charge on the oxygen of the ketone group is increased, so that the electrostatic repulsions now become more significant than the non-bonded interactions of *one* of the groups in the e′ position, with the result that the e′a′ (greater group separation) is now more stable than the a′a′ conformation (*i.e.*, *cis* → *trans*). The *cis*-diacid (Table 2, first compound) is inverted to the *trans*-isomer not only under alkaline conditions (two anionic groups present) but also by heat alone or in the presence of acid, indicating that the electrostatic repulsions even in the un-ionised molecule are sufficient to result in the e′a′ conformation's being more stable than the a′a′, despite the increased non-bonded interactions obtaining in the former. The other inversions recorded in Table 2 may be interpreted similarly.

The geometry of addition products from anthracenes and anthraquinones, and of substitution products of dihydroanthracenes, can be explained in similar terms. Three examples suffice for the present. *cis*-Diacids are the major products of carbonation of sodio-derivatives of anthracene and certain dialkylanthracenes (Beckett, Lingard, and Mulley, unpublished work) because the reaction occurs most readily if the entering carboxylate ion enters the a′ position to yield an a′a′ (*i.e.*, *cis*-)isomer, despite the fact that the *trans*-diacid (or dianion) is the thermodynamically more stable. Similarly there is *cis*-addition of chlorine to 1 : 5-dichloroanthracene and 9 : 10-diphenylanthracene (Bergmann and Weizmann, *loc. cit.*), and reaction of methyl iodide with the sodio-derivative of anthracene yields *cis*-9 : 10-dihydro-9 : 10-dimethylanthracene (Badger *et al.*, *loc. cit.*).

Experimental

Microanalyses were by Mr. Crouch, School of Pharmacy, London University. Equivalent weights of the bases were determined by titration with 0·02N-perchloric acid in glacial acetic acid with crystal-violet as indicator. Hydrochlorides were titrated similarly in the presence of mercuric acetate (see Pifer and Wollish, *J. Amer. Pharm. Assoc., Sci. Ed.*, 1951, **40**, 609). Infrared spectra were obtained on a Perkin-Elmer Model 21B double-beam automatic recording

spectrophotometer equipped with a rock-salt prism, the compounds being as solid mulls in Nujol. M. p.s were determined by introducing a capillary tube containing the sample into a heated block 10° below the m. p. and raising the temperature at about 5—10° per min.

9 : 10-*Dihydroanthracene*-9 : 10-cis-*dicarboxylic Anhydride*.—Prepared as described by Beckett *et al.* (*loc. cit.*) the anhydride had m. p. 194—195°. Mathieu and Rigaudy (*locc. cit.*) give m. p. 233—234° (block). Their anhydride, kindly supplied by Dr. Rigaudy, melted at 194—195° when the capillary-tube method was used; the m. p. did not vary significantly with the rate of heating.

Methyl cis-9-*Carboxy*-9 : 10-*dihydroanthracene*-10-*carboxylate* (II*b*).—Finely powdered anhydride (2 g.) was refluxed with methanol (8 ml.) and pyridine (15 drops) until dissolved. Ether (30 ml.) was added and the solution extracted with dilute hydrochloric acid. Evaporation of the solvent gave the monoester (2·25 g.), m. p. 165—170°, contaminated with about 10% of diester. The former was extracted with saturated sodium hydrogen carbonate solution and recrystallised from butyl ether, to give the *cis*-monoester, m. p. 182—184° (Found : equiv., 143. Calc. for $C_{17}H_{14}O_4$: equiv., 141). Rigaudy (*loc. cit.*) gave m. p. 184—185°; Beckett *et al.* (*loc. cit.*) reported m. p. 181—182°.

Alkaline hydrolysis. The ester was refluxed for 15 min. with dilute sodium hydroxide solution. Acidification of the solution gave the *trans*-diacid (III*a*), m. p. and mixed m. p. 309—310°.

Acid hydrolysis. This gave the *cis*-diacid (II*a*) only (no inversion; see preparation of the *cis*-diacid).

9 : 10-*Dihydroanthracene*-cis-9 : 10-*dicarboxylic Acid* (II*a*).—The *cis*-monomethyl ester (II*b*) (0·5 g.) was heated in acetone (5 ml.) and concentrated hydrochloric acid (10 ml.) at 120° for 1 hr. Water was added and the solid (0·34 g.) filtered off and washed with water and ether. Recrystallisation from glacial acetic acid (2 ml.) gave the *cis*-9 : 10-dicarboxylic acid as cubes (Found : C, 72·2; H, 4·8%; equiv., 130. Calc. for $C_{16}H_{12}O_4$: C, 71·6; H, 4·5%; equiv., 134), which melted partially at 265—266° and then solidified and remelted at 301—302° (decomp.). Mathieu (*loc. cit.*) reported m. p. 283° (block) and Schlenk (*loc. cit.*) m. p. 294°.

Isomerisation. (*a*) This *cis*-diacid was heated with aqueous alkali to give the *trans*-diacid (III*a*) (cf. Mathieu, *loc. cit.*). (*b*) The *cis*-diacid, heated in a m. p. apparatus at 270° for 1 min., gave the *trans*-diacid (III*a*) (identified by m. p. 301—302° and infrared absorption). (*c*) The *cis*-diacid (54 mg.) was heated with concentrated hydrochloric acid (3 ml.) at 120° for 16 hr. A mixture of *cis*- (37 mg., cubes, m. p. 265—266°) and *trans*-diacid (9 mg., needles, m. p. 309—310°) was obtained.

9 : 10-*Dihydroanthracene*-trans-9 : 10-*dicarboxylic Acid* (III*a*).—Finely powdered anhydride (2 g.) was boiled with 5% sodium hydroxide solution (20 ml.) for 30 min. and the solution acidified, to give a solid (2·07 g.), m. p. 300°. Recrystallisation of this material (0·75 g.) from acetic acid (80 ml.) gave the 9 : 10-*trans*-acid (0·14 g.) as needles, m. p. 309—310° (decomp.) (Found : C, 70·9; H, 4·4%; equiv., 132·5). Mathieu (*loc. cit.*) reported m. p. 380° (block), Schlenk (*loc. cit.*) m. p. 286°, and Beyer and Fritsch (*Ber.*, 1941, **74**, 494) m. p. 305—307°.

Attempted isomerisation. (*a*) The *trans*-diacid was heated under the conditions described for the *cis*-isomer and gave unchanged material (m. p. and infrared spectrum unchanged). (*b*) Heating with concentrated hydrochloric acid (conditions as for the *cis*-isomer) gave unchanged material, m. p. 309—310° (decomp.).

9 : 10-*Dihydro*-9 : 10-*dimethylanthracene*-9 : 10-cis-*dicarboxylic Anhydride*.—Prepared by the method described by Beckett *et al.*, the anhydride had m. p. 215—216°. It gave *cis*-diacid only (no inversion; see preparation of the *cis*-diacid).

9 : 10-*Dihydro*-9 : 10-*dimethylanthracene*-cis-9 : 10-*dicarboxylic Acid* (IV*a*).—The foregoing anhydride (0·2 g.) was heated with dilute sodium hydroxide solution until dissolved. The acid was precipitated with dilute hydrochloric acid and recrystallised from glacial acetic acid to give cubes (0·15 g.) of the 9 : 10-cis-*diacid*, m. p. 310—312° (decomp.) (Found : C, 72·8; H, 5·5; equiv., 150. $C_{18}H_{16}O_4$ requires C, 73·0; H, 5·4%; equiv., 148).

The acid was stable when heated alone or with aqueous alkali. Heating the diacid with acetic anhydride regenerated the anhydride.

9 : 10-*Dihydro*-9 : 10-*dimethylanthracene*-trans-9 : 10-*dicarboxylic Acid* (IV*a*).—A mixture of crude acids (2·7 g.) prepared by carbonation of the sodium addition compound of dimethylanthracene (*idem*, *loc. cit.*) was heated with acetic anhydride (6 ml.), chloroform (20 ml.) was added, and the *trans*-diacid (50 mg.) extracted with saturated sodium hydrogen carbonate solution. Recrystallisation from glacial acetic acid gave the 9 : 10-trans-*diacid* as needles, m. p. 347—348° (decomp.; sealed capillary) (Found : C, 72·7; H, 5·5%).

Heating the *trans*-diacid with acetic anhydride [same conditions as for the *cis*-diacid (IV*a*)] gave unchanged diacid.

Methyl cis-9-*Carboxy*-9 : 10-*dihydro*-9 : 10-*dimethylanthracene*-10-*carboxylate* (IV*b*).—The dimethyl-anhydride (0·35 g.) was refluxed with methyl alcohol (3 ml.) and pyridine (6 drops) (as described for the parent anhydride) to give the *monomethyl ester* contaminated with about 10% of diester. The former recrystallised from butyl ether as solvated cubes, m. p. 157—158° (material for analysis was recrystallised from benzene; difficulties were experienced in obtaining consistent analytical figures owing to explosion during combustion) (Found: C, 72·5; H, 5·6. $C_{19}H_{18}O_4$ requires C, 73·5; H, 5·8%).

cis-9-*Carboxy*-9 : 10-*dihydroanthracene*-10-*carboxymorpholide* (II*d*).—The *cis*-amido-ester (II*c*) (0·22 g.), as a fine powder, was heated at 120° for 1 hr. with concentrated hydrochloric acid (5 ml.). The solid product was filtered off and recrystallised from glacial acetic acid to give cubic crystals of the *monomorpholide*, m. p. 266—269° (Found: C, 71·1; H, 5·4; N, 4·05%; equiv., 334. $C_{26}H_{19}O_4N$ requires C, 71·2; H, 5·6; N, 4·3%; equiv., 334).

The *cis*-amido-acid (17 mg.) was boiled for 30 min. with dilute sodium hydroxide solution, and the solution acidified to give the *trans*-isomer (6 mg.) (identified by the infrared spectrum and m. p. 225—226°). Heating the *cis*-amido-acid under the conditions described for the *trans*-isomer gave unchanged *cis*-amido-acid (infrared spectrum).

trans-9-*Carboxy*-9 : 10-*dihydroanthracene*-10-*carboxymorpholide* (III*d*).—The anhydride (14 g.) was heated with morpholine (32 ml.) until dissolved. The solution was then cooled and acidified, and the precipitated solid *morpholide* (18·7 g.) filtered off and recrystallised from butanol to give diamond-shaped crystals, m. p. 225—226° (Found: C, 71·4; H, 5·9; N, 4·3%; equiv., 333).

The *trans*-amido-acid was refluxed for 6 hr. with acetic acid (12·5 ml.) and concentrated hydrochloric acid (7·5 ml.). Upon cooling, crystals (0·15 g.) of the *cis*-amido-acid (identified by m. p. 266—269° and the infrared spectrum) were obtained; a second crop (0·42 g.), m. p. 225—226°, consisted mainly of unchanged *trans*-amido-acid. A few needle-shaped crystals of the *trans*-diacid, m. p. 305—310°, were hand-picked from this second crop.

The *trans*-amido-acid, when heated from 210° to 230° during 3½ min., gave the *cis*-amido-acid (infrared spectrum and m. p. 265°).

The *trans*-amido-acid was boiled for 30 min. with aqueous alkali and gave unchanged material, m. p. 225—226°.

cis-9-*Carboxy*-9 : 10-*dihydro*-9 : 10-*dimethylanthracene*-10-*carboxymorpholide* (IV*d*).—Prepared as described by Beckett *et al.* (*loc. cit.*) the amido-acid had m. p. 291—292°. This acid was unchanged when boiled with dilute sodium hydroxide solution for 30 min.

cis-9-*Methoxycarbonyl*-9 : 10-*dihydroanthracene*-10-*carboxymorpholide* (II*c*).—The *cis*-mono-ester (1·8 g.) was heated with thionyl chloride (3 ml.) until dissolved. Excess of thionyl chloride was removed under pressure, the residue dissolved in ether (25 ml.), morpholine (0·65 g.) in ether (5 ml.) added, and the precipitated solid (1·95 g.) filtered off. Three recrystallisations from butanol gave colourless needles of the cis-*ester-morpholide*, m. p. 212—214° (Found: C, 72·0; H, 5·8; N, 4·2%; equiv., 354. $C_{21}H_{21}O_4N$ requires C, 71·8; H, 6·0; N, 4·0%; equiv., 351).

The *cis*-amido-ester (61 mg.) was refluxed with 0·1N-sodium hydroxide for 5 min. Acidification of the solution gave the *trans*-amido-acid (53 mg., complete inversion) identified by m. p. 225—226° and the infrared spectrum. The *cis*-amido-ester was recovered unchanged (m. p. and infrared spectrum) when heated from 210° to 230° during 3½ min. Acid-hydrolysis gave the *cis*-amido-acid (no inversion; see preparation of the *cis*-amido-acid).

trans-9-*Methoxycarbonyl*-9 : 10-*dihydroanthracene*-10-*carboxymorpholide* (III*c*).—*Method A. trans*-Amido-acid (III*d*) (0·65 g.) was treated with a large excess of diazomethane in ether (50 ml.) at room temperature. A little insoluble material was filtered off and the ether removed. Recrystallisation from benzene gave colourless plates (0·34 g.) of trans-*ester-morpholide*, m. p. 161—162·5° (Found: C, 71·8; H, 6·2. $C_{21}H_{21}O_4N$ requires C, 71·8; H, 6·0%). *Method B.* The *trans*-amido-acid (0·77 g.) was refluxed with methanol (10 ml., containing 1% of hydrogen chloride) for 3 hr. Water (100 ml.) and benzene (60 ml.) were added and the separated aqueous layer was extracted with more benzene (20 ml.). The mixed benzene fractions were evaporated to give a solid, m. p. 156—158°, softening at 150°. Recrystallisation from butyl ether gave crystals of two types which were separated by hand-picking: colourless plates (0·62 g.) of the *trans*-amido-ester (III*c*), m. p. 161—162·5, and needles (80 mg.) of the *cis*-amido-ester, m. p. 212—214°.

The *trans*-amido-ester (50 mg.) was refluxed for 10 min. with 0·1N-sodium hydroxide.

Acidification of the solution gave the *trans*-amido-acid (40 mg.; no inversion), m. p. and mixed m. p. 225—226°. The *trans*-amido-ester was unchanged by heat (infrared spectrum).

trans-*Ethoxycarbonyl*-9 : 10-*dihydroanthracene*-10-*carboxymorpholide*.—Prepared from the *trans*-amido-acid (8·2 g.) as described for the methyl ester (method B), the *ethyl ester* (4 g.) had m. p. 118—118·5° (Found : C, 71·7; H, 6·5; N, 3·9. $C_{22}H_{23}O_4N$ requires C, 72·3; H, 6·3; N, 3·8%).

cis-9-*Methoxycarbonyl*-9 : 10-*dihydro*-9 : 10-*dimethylanthracene*-10-*carboxymorpholide* (IV*c*).—*Method A. cis*-Monomethyl ester (IV*b*) (0·13 g.) was refluxed with thionyl chloride (0·5 ml.) until dissolved and excess of reagent was removed under reduced pressure. The crude acid chloride in ether (5 ml.) was treated with morpholine (45 mg.) in ether (2 ml.), the mixture extracted with dilute acid, and the organic layer evaporated. Recrystallisation from butyl ether gave the cis-*ester-morpholide* (56 mg.), m. p. 157—158°, as plates (Found : C, 73·2; H, 6·4; N, 3·8. $C_{23}H_{25}O_4N$ requires C, 72·8; H, 6·65; N, 3·7%). *Method B.* The *cis*-amido-acid (0·36 g.) was treated with excess of diazomethane in ether. The ether was removed and the ester recrystallised from butyl ether to give the *cis*-amido-ester (0·1 g.), m. p. 157—158°

9-*Acetyl*-9 : 10-*dihydroanthracene*-10-*carboxymorpholides* (II*h and* III*h*).—Powdered *trans*-amido-acid (III*d*) (2 g.) was refluxed with thionyl chloride (4 ml.) until dissolved. Excess of thionyl chloride was removed and the gummy acid chloride then run slowly in benzene (25 ml.), with vigorous stirring, into a solution of diethylcadmium (from 2·6 g. of anhydrous cadmium chloride, 0·68 g. of magnesium, and 3·06 g. of ethyl bromide) in ether (100 ml.) in a nitrogen atmosphere. An immediate precipitate changing to a gum was formed. The mixture was stirred and refluxed for 30 min., the complex decomposed with ice and dilute sulphuric acid, the organic layer separated, and the acidic layer extracted with benzene (20 ml.). The organic fractions were extracted with saturated sodium hydrogen carbonate solution, washed with water, dried, and evaporated, to give a gum (1·5 g.) (acidification of the sodium hydrogen carbonate solution gave 0·5 g. of unchanged *trans*-amido-acid, m. p. and mixed m. p. 225—226°). The gum was dissolved in benzene (3 ml.) and gave, on storage, colourless needles (0·16 g.), m. p. 214—215°. Recrystallisation from benzene gave the cis-*morpholido-ketone*, m. p. 219—220° (Found : C, 75·7; H, 6·6; N, 4·0. $C_{22}H_{23}O_3N$ requires C, 75·6; H, 6·6; N, 4·0%). Evaporation of the benzene mother-liquors gave a solid which, recrystallised from ethanol, gave colourless blades (0·35 g.) of trans-*morpholido-ketone*, m. p. 139—139·5°, containing ethanol of crystallisation (material for analysis was heated at 100° under reduced pressure for 30 min. : the m. p. was unchanged) (Found : C, 75·9; H, 6·9%).

The *cis*-amido-ketone (20 mg.) in ethanol (3 ml.) was boiled with 2 : 4-dinitrophenylhydrazine reagent (1 ml. of a 5% solution in ethanol–sulphuric acid), to give the 2 : 4-*dinitrophenylhydrazone*, yellow needles, m. p. 265—266° (decomp.) (Found : C, 63·9; H, 5·15; N, 13·4. $C_{28}H_{27}O_6N_5$ requires C, 63·5; H, 5·1; N, 13·4%).

The *trans*-amido-ketone (48·5 mg.) in ethanol (0·5 ml.), boiled with 2 : 4-dinitrophenylhydrazine reagent (2 ml.), gave a yellow solid (30 mg.), m. p. 185—200°. Recrystallisation from acetone gave yellow needles of the *cis*-2 : 4-dinitrophenylhydrazone (*i.e.*, partial isomerisation), m. p. and mixed m. p. 265—266°. Evaporation of the alcoholic mother-liquors gave material (27 mg.), m. p. 163—165°. Recrystallisation from ethanol gave the trans-2 : 4-*dinitrophenylhydrazone* (18·6 mg.) as yellow needles, m. p. 187—189° (Found : C, 63·9; H, 5·4; N, 13·2%).

Isomerisation of the cis- *and* trans-*Keto-morpholides*.—(*a*) The *trans*-compound (9 mg.) was heated at 120° for 1 hr. with concentrated hydrochloric acid (0·5 ml.). Water (2 ml.) was added and the precipitated solid recrystallised from ethanol (0·25 ml.), to give the *cis*-isomer (0·4 mg.), m. p. and mixed m. p. 215—216°. (*b*) The *cis*- and *trans*-ketones were heated from 210—230° during 3½ min. : the isomers were unchanged (m. p. and infrared spectra).

cis-9 : 10-*Dihydro*-9-*hydroxymethyl*-10-*morpholinomethylanthracene* (II*e*).—The *cis*-amido-ester (II*c*) (1·0 g.) in dry benzene (50 ml.) was added to excess of lithium aluminium hydride in dry ether, the mixture refluxed for 6 hr., and excess of reducing agent destroyed by the addition of water. The solvent was decanted through a filter, the inorganic material extracted with benzene, and the base extracted from the organic solvent with dilute acid. The base was precipitated with alkali and taken up in ether, and the ether evaporated, to give a solid (0·81 g.). Recrystallisation from ethanol gave colourless cis-*alcohol*, m. p. 118—119·5° (Found : C, 78·0; H, 7·4; N, 4·6%; equiv., 308·5. $C_{20}H_{23}O_2N$ requires C, 77·6; H, 7·5; N, 4·5%; equiv., 309·5). The *hydrochloride* had m. p. 279—282° (decomp.) (Found : C, 69·3; H, 6·6%; equiv., 344·5. $C_{20}H_{24}O_2NCl$ requires C, 69·4; H, 7·0%; equiv., 346), and the *picrate* m. p. 202—203° (decomp.) (Found : C, 58·4; H, 5·0; N, 10·7. $C_{26}H_{26}O_9N_4$ requires C, 58·0; H, 4·9; N, 10·4%).

A similar reaction in the *trans*-series gave the *trans*-alcohol (0·45 g. from 2·5 g.) as a gum which gave a *hydrochloride*, m. p. 280—282° (decomp.) (Found : C, 69·9; H, 6·9%; equiv., 348) [mixed m. p. with the *cis*-hydrochloride 269—270° (decomp.)], and a *picrate*, m. p. 202—204° (decomp.) (Found : C, 58·0; H, 5·1; N, 10·7%) [mixed m. p. with the *cis*-picrate 181—189° (decomp.)]. A non-basic compound (1·53 g.) was isolated from the organic solvent after extraction of the base and recrystallised from benzene, yielding trans-9 : 10-*dihydro*-9-*hydroxymethylanthracene*-10-*carboxymorpholide* (III*g*), m. p. 165—166° (Found : C, 74·8; H, 6·6; N, 4·3. $C_{26}H_{21}O_3N$ requires C, 74·3; H, 6·5; N, 4·3%).

cis-9 : 10-*Dihydro*-9-1′-*hydroxypropyl*-10-*morpholinomethylanthracene* (III*i*).—The *cis*-amido-ketone (II*h*) (0·6 g.) was reduced with lithium aluminium hydride (as previously described) to give the required *base* (0·54 g.), m. p. 113—114° (from ethanol) (Found : C, 78·5; H, 7·8; N, 4·2%; equiv., 333·5. $C_{22}H_{27}O_2N$ requires C, 78·3; H, 8·1; N, 4·15%; equiv., 337·5).

The *trans*-amido-ketone (III*h*) (1·05 g.), when similarly reduced, gave a base as a gum (0·15 g.) and a non-basic substance (0·87 g.), trans -9 : 10-*dihydro*-9-1′-*hydroxypropylanthracene*-10-*carboxymorpholide* (III*j*), m. p. 151—153° (from benzene) (Found : C, 74·9; H, 7·2; N, 4·2. $C_{22}H_{25}O_3N$ requires C, 75·2; H, 7·2; N, 4·0%). Attempts to crystallise the basic gum, or to produce derivatives of the base, were unsuccessful.

cis-9-*Acetoxymethyl*-9 : 10-*dihydro*-10-*morpholinomethylanthracene* (II*f*).—The *cis*-amino-alcohol (II*e*) (0·3 g.) in dry ether (15 ml.) was added to ethylmagnesium iodide (from 0·1 g. of magnesium and 0·63 g. of ethyl iodide) in ether with vigorous stirring, and the mixture refluxed for 15 min. Acetic anhydride (2 ml.) in ether (10 ml.) was slowly added to the cooled suspension, and the mixture stirred overnight at room temperature (see Beckett and Linnell, *J. Pharm. Pharmacol.*, 1950, **2**, 430). Dilute hydrochloric acid was added, non-basic material extracted with ether, the solution made alkaline, and the precipitated base extracted with ether. Evaporation of the solvent gave the acetate (0·29 g.) as a gum, which afforded a *hydrochloride* (0·25 g.), m. p. 237—239° (decomp.) (Found : C, 68·3; H, 6·75; N, 3·5%; equiv., 389·5. $C_{22}H_{26}O_3NCl$ requires C, 68·1; H, 6·75; N, 3·6%; equiv., 387·5), and a *picrate*, m. p. 208—209° (decomp.) (Found : C, 57·6; H, 5·0; N, 9·6. $C_{28}H_{28}O_{10}N_4$ requires C, 57·9; H, 4·9; N, 9·6%). Acetylation of the *cis*-amino-alcohol with acetyl chloride in the presence of pyridine gave similar results.

The crude *trans*-amino-alcohol (III*e*) (0·39 g.) was treated with ethylmagnesium iodide and acetic anhydride (10 ml.) as above. The mixture was refluxed for 6 hr. and the base obtained as a gum. Part (22 mg.) of the gum in ethanol, with picric acid (19·5 mg.) in ethanol, gave a yellow solid (28·5 mg.), m. p. 167—170°; recrystallisation from ethanol gave crystals of two types which were separated by hand-picking and gave the *picrate* of the *trans*-acetate as clusters of needles, m. p. 181—182° (decomp.) (11 mg.; from acetone–ethanol) (Found : C, 58·4; H, 5·0; N, 9·4%), and discrete needles, m. p. 202—204° (decomp.), of unacetylated amino-alcohol picrate.

The *trans*-amino-ester picrate (23·5 mg.) in acetone (3 ml.) was decomposed with 5% lithium hydroxide solution, and the base extracted with ether. Evaporation of the solvent gave the base (11 mg.) which formed the trans-*amino-acetate hydrochloride*, needles, m. p. 256—257° (decomp.) (from ethanol–ether).

cis-9-1′-*Acetoxypropyl*-9 : 10-*dihydro*-10-*morpholinomethylanthracene*.—The *cis*-amino-alcohol (II*i*) (0·4 g.) was refluxed with acetyl chloride (2 ml.), and the reagent then removed under reduced pressure to give the required base. This was treated with picric acid to give the *ester picrate*, m. p. 178—179° (Found : C, 58·8; H, 5·4; N, 9·1. $C_{30}H_{32}O_{10}N_4$ requires C, 59·2; H, 5·4; N, 9·2%). The base formed a *hydrochloride*, m. p. 187—190° (Found : C, 68·7; H, 6·7%; equiv., 420. $C_{24}H_{30}O_3NCl$ requires C, 69·3; H, 7·3%; equiv., 416).

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Studies in Spectroscopy. Part VIII. The* N–H *Vibration in Secondary Amines.*

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[Reprint Order No. 6259.]

The infrared spectra of dimethylamine, diethylamine, and their trifluoro-derivatives have been measured, and the N–H stretching and deformation bands have been assigned.

Primary alkylamines show two absorption bands in the NH stretching region (3 μ) arising from the symmetric and asymmetric vibrations, and an NH_2 deformation absorption near 6·2 μ. Secondary alkylamines show only a single NH stretching vibration near 3 μ and the NH deformation absorption expected at 6·2—6·5 μ is apparently absent or is too weak to be of use diagnostically. These correlations have been obtained from spectra of liquid amines, their solutions, or of mulls of solid amines. In connection with a study of bisperfluoroalkylamines (*J.*, 1955, 2532), the infrared spectra of the secondary amines dimethylamine, diethylamine, bis-2 : 2 : 2-trifluoromethylamine, and bistrifluoromethylamine have been recorded, since these compounds enable the effect of progressive increase in negativity of the alkyl groups on the NH stretching and deformation vibrations to be studied. Russell and Thompson (*J.*, 1955, 483) have recently studied the spectra of a number of unsubstituted amines and have noted the marked change in strength of the NH band with structure of the amine.

The NH stretching vibration at 2·99 μ for dimethylamine vapour is extremely weak (ε 0·7) and would be missed unless high pressures were used (see Fig.). Diethylamine vapour similarly shows only a very weak NH stretching vibration at 3·00 μ (ε 0·3, see Fig. and Table). Neither amine has a band in the 6—7-μ region which can immediately be assigned to the NH deformation vibration, although it is possible that this vibration might be masked by the CH deformation band centred on 6·8 μ which shows several small side bands and inflections (see Fig.). The CH_2 and CH_3 stretching vibrations appear as a doublet at 3·37, 3·55 μ.

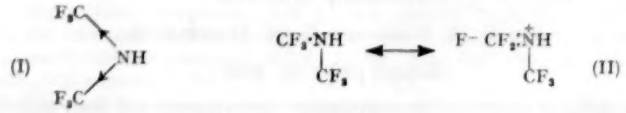
The spectrum of bis-2 : 2 : 2-trifluoroethylamine vapour shows a well-defined NH stretching vibration at 2·92 μ, *i.e.*, at a wavelength distinctly shorter than that for the unsubstituted dialkylamines; the intensity is also markedly increased (ε 5·3; see Fig.). The CH_2 stretching vibration is at 3·40 μ and the CH_2 deformation vibration can be assigned either to the strong band at 6·67 μ (ε 28·0) or to one or more of the weaker bands which immediately follow it (see Fig.). The 6·67-μ band is probably the NH deformation vibration, however, [cf. $(CF_3)_2NH$, p. 4170], and strong support for this assignment is given by the spectra of *N*-nitrobis-2 : 2 : 2-trifluoroethylamine and *N*-nitrosobis-2 : 2 : 2-trifluoroethylamine (C.S. No. 233). In these compounds the N–H bond is absent, and the 6·67-μ band disappears from the spectra, whereas the pattern and position of the weaker bands near 7 μ remain virtually unchanged (see Fig.); one or more of these weaker bands can thus be assigned to the CH_2 deformation vibration.

The NH stretching vibration for liquid diethylamine and bis-2 : 2 : 2-trifluoroethylamine is at a longer wavelength (3·05 and 2·95 μ respectively) than in the vapour spectra, revealing the effect of hydrogen bonding possible in the liquid. The intensity of the NH vibration is almost the same for the two liquids (see Table).

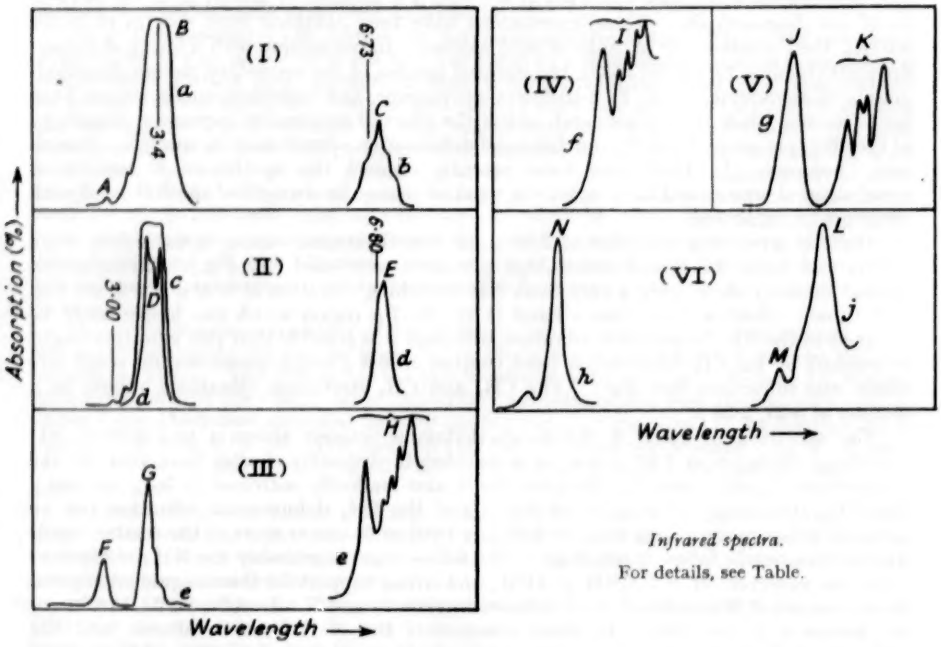
The infrared spectrum of bistrifluoromethylamine is most interesting. The NH stretching vibration appears at 2·89 μ thus continuing the shift to shorter wavelength with increase in negativity of the alkyl group of the secondary amine; this increase in negativity also causes a large increase in intensity (ε 43) associated with the positive character of the hydrogen atom (see Fig.). The inductive effect of the trifluoromethyl groups (I) and the hyperconjugation effect of fluorine (II) (*J.*, 1952, 3490; 1953, 992) act in the same direction.

* Part VII, *J.*, 1954, 4145.

There are two bands in the 6—7-μ region which require explanation (see Fig.). The weak band at 6·19 μ (ε 11) could be assigned to the NH deformation vibration of bistrifluoromethylamine. This would mean that this vibration is increased in intensity relative



to that in dimethylamine or diethylamine which do not show a band in this region of the spectrum; support for this would be given by the fact that the intensity of an NH deformation band is enhanced by attachment of other electron-attracting groups to nitrogen, *e.g.*, as in *N*-alkylamides which show a band at 6·4—6·6 μ: $-C(:O)NH- \longleftrightarrow -C(O^-){:}\overset{+}{N}H-$.



Infrared spectra.

For details, see Table.

The possibility of assigning the 6·65-μ band to the NH deformation vibration must also be considered. In favour of this assignment is first the difficulty of assigning it to anything else, since a band of such intensity (ε 310) cannot be ignored; it is not one of the C–F stretching vibrations which lie in the usual region *ca.* 8 μ (7·39, 7·92, 8·33, 8·73 μ). Secondly, there is no possibility of confusion with CH_2 deformation vibrations. Thirdly, the band is at the same position as the 6·67-μ band of bis-2 : 2 : 2-trifluoroethylamine, which is plausibly assigned to the NH deformation vibration. The main argument against this assignment of the 6·65-μ band is its extremely high extinction coefficient (ε 310). The increase in intensity parallels that of the NH stretching band (2·89 μ) relative to the corresponding band in bis-2 : 2 : 2-trifluoroethylamine, however, and the evidence thus favours the 6·65-μ band as the NH deformation vibration.

If these assignments for the fluoroalkylamines are correct, then it becomes possible that the corresponding vibration in dimethylamine and diethylamine is masked by the CH_2

deformation vibration at 6·8 μ; examination of the last band does reveal a side peak or inflection at 6·73 μ for dimethylamine and 6·80 μ for diethylamine; the intensities of these bands are similar to that of the 6·67-μ band in bis-2 : 2 : 2-trifluoroethylamine. These bands are tentatively assigned to the NH deformation vibration, and a detailed investigation of other dialkylamines in the 6·6—6·9-μ region of the spectrum is clearly merited.

Experimental

Spectra were recorded by a Perkin-Elmer Model 21 double beam spectrometer with sodium chloride optics. A 10-cm. gas cell was used for vapour spectra, and the extinction coefficient, ε, was calculated from the expression $\varepsilon = (D \times 760 \times 22{\cdot}4 \times 290)/10 \times p \times 273$ where D = optical density, and p is the pressure in mm. The percentage absorption at a particular wavelength was measured from a base-line drawn through the background (points of zero absorption) of the spectrum; since a balancing absorption cell was not used, this background was usually at 25—30% of the full scale deflection. The extinction coefficients are thus not absolute values, but since the same cell was used for all the vapour spectra, under precisely the same conditions, and with the same base line and slit programme, the ε values can be compared with each other. Russell and Thompson (*loc. cit.*) have discussed the dangers of using extinction coefficients, and have employed integrated band areas as a more precise method of comparison of the fundamental NH vibration of various secondary amines, but extinction coefficients have been used for the present comparisons since one is considering 10-fold changes in ε, and the errors involved by changes in the apparent half band widths are relatively small. The comparisons are clearly only semi-quantitative, however, particularly since a rock-salt prism, which has poor resolving power in the 3-μ region, was used. The following slit widths were used:

Wavelength (μ)	2·89	2·95	3·00	3·05	6·15	6·19	6·65
Slit (μ)	37	38	39	39	70	71	75

Sealed cells (nominally 0·025 and 0·050 mm.) and capillary films were used to obtain spectra of the liquids. The results are summarised in the annexed Table.

					3-μ band ‡			6—7-μ band ‡			CH_3 vibrations ‡	
Compound	Graph	C.S. no.	State *	p † (mm.)	λ	Abs. (%)	ε	λ	Abs. (%)	ε	Stretching (λ)	Deformation (λ)
Me_2NH	(I)	249	V	38 *a*	2·99 *A*	4·0	0·8	Not certain			3·39 *B*	—
				660	2·99	38·0	0·6	,,			3·57	—
				15 *b*	—	—	—	—	—	—	—	6·73 (infl., ε 20), 6·82 *C*,
Et_2NH	(II)	248	V	95 *c*	3·00	3·0	0·2	Not certain			—	—
				14 *d*	—	—	—	,,			3·37 *D*, 3·55 *D*	6·80, 6·87 *E*, 7·20
$(CF_3{\cdot}CH_2)_2NH$...	(III)	246	V	39 *e*	2·92 *F*	23·0	5·3	6·67	75·0	28	3·40 *G*	6·67 *H*, 6·87 *H*, 6·97 *H*, 7·07 *H*, 7·21 *H*
$(CF_3{\cdot}CH_2)_2NH$...	(IV)	245	L	0·25 *f*	2·95	50·0	—	6·67	83·0	—	3·42	6·67 *I*, 6·87 *I*, 6·97 *I*, 7·07 *I*, 7·20 *I*
$(CF_3{\cdot}CH_2)_2N{\cdot}NO_2$	(V)	243	C	*g*	—	—	—	6·32 *J*	—	—	—	6·95 *K*, 7·07 *K*, 7·16 *K*, 7·40 *K*,
$(CF_3)_2NH$	(VI)	244	V	2	—	—	—	6·65	54·5	310	None	None
				2	—	—	—	6·19	—	—		
				5	2·89	76·5	42	6·65	86·0	310		
				5	—	—	—	6·15	—	—		
				15 *j*	2·89	56·0	43	6·65 *L*	—	—		
				15 *j*	—	—	—	6·19 *M*	19·0	11		
				150 *h*	2·89 *N*	—	—	6·65	—	—		
				150	—	—	—	6·19	86·0	10		
Et_2NH	—	247	L	0·025	3·05	51·5	—	Not certain			3·37, 3·46, 3·55	6·73 (infl., 75% absorption), 6·87, 7·25

* V, vapour; L, liquid; C, capillary film.
† Pressure (gas) or thickness (liquid). Letters define relevant curve in Figure.
‡ Capital italic letters define regions of curves in the Figure in which the maxima occur.

Dimethylamine (Found : *M*, 46·0. Calc. for C_2H_7N : *M*, 45·0) and diethylamine (Found : *M*, 72·0. Calc. for $C_4H_{11}N$: *M*, 73·0) were commercial samples, dried and fractionated *in vacuo*.

Bis-2 : 2 : 2-trifluoroethylamine, b. p. 82°, was dried and redistilled immediately before use (Found : *M*, 181. Calc. for $C_4H_5NF_6$: *M*, 181).

N-Nitrobis-2 : 2 : 2-trifluoroethylamine shows bands at 6·95, 7·07, and 7·16 μ closely similar to those of bis-2 : 2 : 2-trifluoroethylamine. The asymmetric stretching vibration of the NO_2 group at 6·32 μ does not overlap the region under consideration.

N-Nitrosobis-2 : 2 : 2-trifluoroethylamine was prepared by B. J. H. Mattinson; the region between the N:O stretching vibration (6·5 μ) and the bands at 7·02 and 7·05 μ is devoid of even weak peaks. The spectrum is discussed further in the following paper.

The authors thank Professor G. F. Wright for a gift of bis-2 : 2 : 2-trifluoroethylamine and *N*-nitrobis-2 : 2 : 2-trifluoroethylamine. One of them (D. A. B.) is indebted to Imperial Chemical Industries, Plastics Division, for a maintenance allowance.

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Studies in Spectroscopy. Part IX. Further Studies on Nitrosamines and Nitrites.*

By R. N. HASZELDINE and B. J. H. MATTINSON.

[Reprint Order No. 6441.]

The ultraviolet spectrum of a dialkylnitrosamine is shifted up to 30 mμ, with loss of fine structure, on change of solvent from light petroleum to water, and intermediate shifts are obtained with other solvents. Further studies of the infrared spectra of the nitrosamines have shown that only in the vapour state is the nitroso-group unaffected by the strong interactions which can be detected in the spectra of liquid nitrosamines or of the nitrosamines in non-polar solvents. Both ultraviolet and infrared spectroscopic results are best explained by assuming either intermolecular dipolar interaction or partial dimerisation of the nitroso-compounds to give $R_2N{\cdot}N(O^-){\cdot}N^+(:O){\cdot}NR_2$ analogous to *C*-nitroso-dimers. Further studies on the ultraviolet and infrared spectra of nitrites support the postulate of rotational isomerism in these compounds. 2 : 2 : 2-Trifluoroethyl nitrite exists mainly as the *trans*-isomer.

These results are applied to the dimer of trifluoronitrosomethane (*J.*, 1954, 696), and it is concluded that the new spectroscopic evidence now favours structure $(CF_3)_2N{\cdot}O{\cdot}NO$ rather than $(CF_3{\cdot}O)(CF_3)N{\cdot}NO$.

A STUDY of the ultraviolet and infrared spectra of nitrosamines and nitrites was recorded in Part VI (Haszeldine and Jander, *J.*, 1954, 691). Further studies have been made and the earlier conclusions can now be expanded and, in one respect, modified.

(I) *Nitrosamines.*—(a) *Ultraviolet spectra.* The ultraviolet spectrum of a nitrosamine resembles that of a nitrite, with a low-intensity maximum at *ca.* 365 mμ which shows fine structure. The marked shift to the blue of this maximum, with loss of fine structure, which occurs when the solvent is changed from light petroleum to ethanol readily distinguishes a nitrosamine from a nitrite (Part VI, *loc. cit.*). This solvent-dependency of the low-intensity nitrosamine band has been investigated in more detail; the results are summarised in Table 1 and typified in Fig. 1. In non-polar solvents such as light petroleum or carbon tetrachloride, the spectrum of dimethyl- or diethyl-nitrosamine is essentially that of the vapour, with the main peak at 363 mμ flanked by peaks of approximately equal intensity. Use of alkyl or cyclic ethers as solvents produces shifts in the main peak of 3—7 mμ, with loss of fine structure (Fig. 1), whereas alcohols cause shifts of 15—16 mμ. Water gives the largest shift (30 mμ).

Dialkylnitrosamines are only very weakly basic, the spectrum of diethylnitrosamine

* Part VIII, preceding paper.

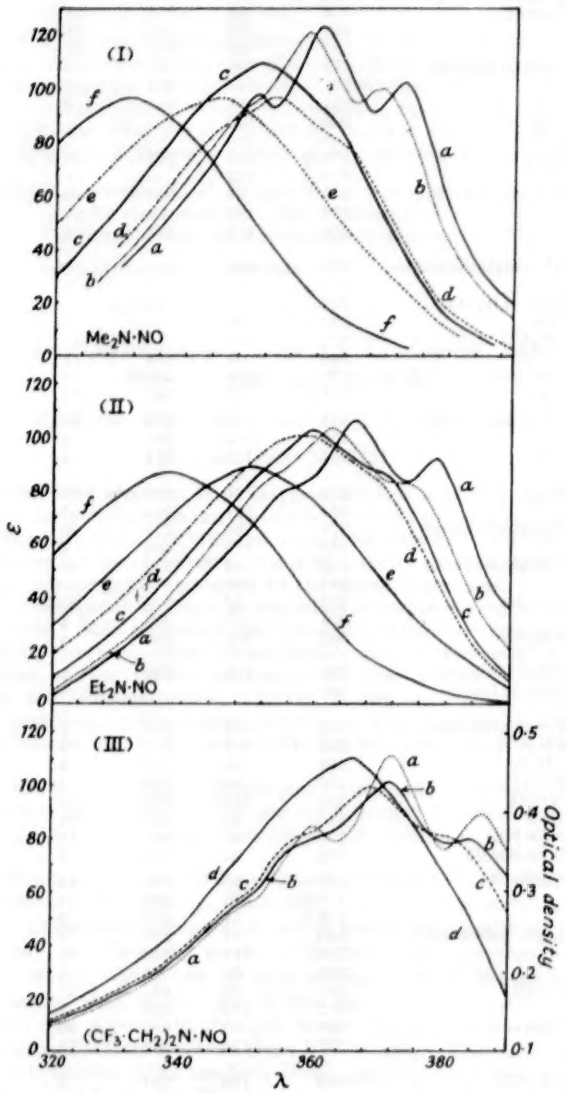
TABLE 1. *Ultraviolet spectra* (300—400 $m\mu$) *of nitrosamines.*

	Solvent	$\lambda_{max.}$	ε	$\lambda_{min.}$	ε	$\lambda_{inf.}$	ε
$Me_2N{\cdot}NO$	Vapour	376	86	371	77	—	—
		363	98	356	78	—	—
		352	83	306	41	—	—
	Light petroleum	374	105	369	90	—	—
		361	125	354	94	—	—
		351	98	301	3	—	—
	CCl_4	360	140	—	—	369	115
		—	—	—	—	352	120
	Et_2O	370·5	102	366	99·5	350	96
		359	123	—	—	—	—
	Tetrahydrofuran	367	99	365·5	98	350	102
		357	122	—	—	—	—
	Dioxan	356	112	298	6	365	92
		—	—	—	—	350	95
	Dimethylformamide	354	100	—	—	364	82
		—	—	—	—	346	89
	Film of liquid	353	—	—	—	360	—
	$CHCl_3$	352	124	—	—	360	110
	$CH_3{\cdot}CN$	352	110	—	—	364	87
	EtOH	346	98	294	11	—	—
	0·1N-HCl–EtOH (1 : 1)	337	103	290	12	—	—
	H_2O	331·5	98	287	12	—	—
$Et_2N{\cdot}NO$	Light petroleum	378	90	374	85	358	82
		366	105	305	3	—	—
	CCl_4	364	104	304	3	373	90
		—	—	—	—	358	90
	Et_2O	376	86	372	82	—	—
		364	101	304	3	—	—
	Tetrahydropyran	374	93	371	90	354	87
		363	110	304	4	—	—
	Tetrahydrofuran	373	85	372	84·5	354	88
		362	103	—	—	—	—
	Dioxan	372	86	371	85·5	—	—
		361	102	304	4	—	—
	NH_2Bu^n	362	103	302	4	370	90
	$CH_2{\cdot}CH{\cdot}CH_2{\cdot}O$	361	104	302	6	370	88
	Film of liquid	360	—	—	—	368	—
		—	—	—	—	350	—
	Dimethylformamide	359	103	302	2	370	87
	$CH_3{\cdot}CN$	358	102	306	9	366	86
	$CHCl_3$	356	110	302	9	363	100
	EtOH	350	90	297	8	—	—
	MeOH	350	110	298	10	—	—
	H_2O	338	88	292	12	—	—
	0·1N-HCl	338	85	291	12	—	—
	0·1N-NaOH	338	87	291	12	—	—
$(CF_3{\cdot}CH_2)_2N{\cdot}NO$	Vapour [1]	386·5	55	381	44	350	33
		372·5	70	365	48	338	19
		359·5	54	307	3	—	—
	Light petroleum [2]	386	91	380	75	350	55
		372	113	364	79	338	30
		360	86	306	5	—	—
	EtOH [2]	385	80	381	77	362	82
		372	103	306	3	350	60
	Dioxan	384	91	380	86	360	88
		371	111	306	11	350	60
		—	—	—	—	338	34
	$CH_3{\cdot}CN$	369	100	304	3	380	81
		—	—	—	—	362	84
	H_2O [4]	366	—	304	—	374	—

[1] Also max. at 230 mμ, ε 4300. [2] Also max. at 230 mμ, ε 5200. [3] Also max. at 230 mμ, ε 5300.
[4] Qualitative measurements on a saturated aqueous solution.

being the same in neutral aqueous, acidic, or basic solution. The shift in the maximum from 331·5 mμ for dimethylnitrosamine in aqueous solution to 337 mμ for a solution in 1 : 1 0·1N-hydrochloric acid–ethanol is thus not caused by the change in pH but by the decrease in dielectric constant of the solvent. Particular attention is drawn to the spectra

FIG. 1. *Ultraviolet spectra of nitrosamines.*



(I) $Me_2N{\cdot}NO$ in (*a*) light petroleum, (*b*) diethyl ether, (*c*) acetonitrile, (*d*) dimethylformamide, (*e*) ethanol, and (*f*) water.
(II) $Et_2N{\cdot}NO$ in (*a*) light petroleum, (*b*) carbon tetrachloride, (*c*) dimethylformamide, (*d*) methyl cyanide, (*e*) ethanol, and (*f*) water.
(III) $(CF_3{\cdot}CH_2)_2N{\cdot}NO$ in (*a*) light petroleum, (*b*) ethanol, (*c*) methyl cyanide, and (*d*) water.

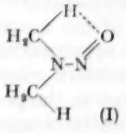
of liquid dimethyl- and diethyl-nitrosamine, which show appreciable change (4—8 mμ shift) from spectra in non-polar solvents, and to the spectra in chloroform which show shifts of 8 mμ relative to spectra in carbon tetrachloride; the spectra as liquid films and in chloroform solution closely resemble those in acetonitrile solution in shape (Fig. 1).

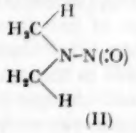
The high-intensity peak near 230 mμ (ε 6000—7000) reported earlier for dialkylnitrosamines (Part VI, *loc. cit.*) remains at 228—233 mμ despite change in solvent, and is unaltered in intensity; the fact that the change in solvent affects only the 365 mμ peak thus strongly suggests that it is the nitroso-group in $R_2N{\cdot}NO$ which is being influenced. The changes in spectra discussed above for dimethyl- and diethyl-nitrosamine occur with the other nitrosamines listed in Part VI.

Possible reasons for the changes in the ultraviolet spectra are: (*a*) complex formation of the neutral-molecule (Lewis) acid-base type as it is shown by iodine, interhalogen compounds, polyfluoroiodo-compounds, and iodine cyanide (see *J.*, **1953**, **2622**; **1954**, **4145** for references); (*b*) rotational isomerism; (*c*) intermolecular dipolar interaction of the nitroso-groups, or true dimerisation of the nitroso-compound as with *C*-nitroso-compounds; (*d*) solvent effects caused by changes in dielectric constant or by hydrogen-bonding of the oxygen atom of the nitroso-group.

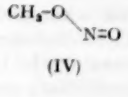
Complex formation, (*a*), can be eliminated at this stage, since the changes in spectra are not related to the (Lewis) basicity of the solvents; strong neutral-molecule Lewis bases such as dimethylformamide or *n*-butylamine, for example, produce smaller effects than weaker bases such as acetonitrile (Table 1).

Rotational isomerism (*b*) brings out the analogy between nitrites and nitrosamines, since both could show such isomerism (see discussion on nitrites below and Part VI). Courtauld models of dimethylnitrosamine can be constructed with either a pyramidal amine-nitrogen, or the more probable amide-type nitrogen [cf. $Me_2N{-}N{=}O \longleftrightarrow Me_2\overset{+}{N}{=}N{-}O^-$ and $CH_3{\cdot}C(:O){\cdot}NH_2 \longleftrightarrow CH_3{\cdot}C(O^-){:}\overset{+}{N}H_2$] for the Me_2N-nitrogen atom. Both models show that the hydrogen atoms approach closely to the oxygen atom, and the most probable structure is (I), where the oxygen atom is either adjacent to one hydrogen atom or equidistant between two hydrogen atoms in a planar configuration; the oxygen atom can


(I)


(II)

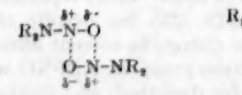
(III)


(IV)

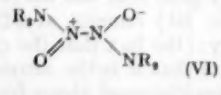
clearly have an equivalent position with respect to the other methyl group. A configuration such as (I) can be regarded as stabilised by weak hydrogen bonding between hydrogen and oxygen, and, though the N–O–H angle is not favourable for hydrogen-bond formation of the usual type, models show that it is much the same as in the alkyl nitrites, where good evidence exists for a *cis*-form (III) and a *trans*-form (IV) (see below). Dimethylnitrosamine could have a second configuration (II), where the oxygen atom is written in parentheses to indicate that it is above the nitroso-nitrogen atom and out of the plane of the nitrogen and carbon atoms. In this non-planar configuration (II), which is less likely in view of the resonance in the >N–N=O system, the oxygen atom would not be bonded to the hydrogen atoms. Rotational isomerism is thus possible in nitrosamines, but less plausible than for nitrites where both (III) and (IV) are distinct planar configurations. On this basis the changes in spectrum from solvent to solvent would be caused by change in the ratio of the rotational isomers present. It is, however, unlikely that rotational isomers would differ by so much in their ultraviolet spectra, particularly since only minor changes are apparent in the ultraviolet spectra of nitrites where the evidence for rotational isomerism is much stronger.

Intermolecular dipolar interaction (*c*), as in (V), to give a weakly bonded dimer, or true dimerisation to give a compound (VI) analogous to a *C*-nitroso-dimer (Haszeldine and Jander, *J.*, 1954, 912), provides the simplest explanation for the ultraviolet and also for the

infrared spectra discussed below. The peaks centred on 360—366 mμ for spectra of vapours or of light petroleum solutions would thus represent the absorption of the monomeric nitrosamine and the shifts to shorter wavelength would be caused by an increasing amount of dipolar interaction or of true dimerisation rendered possible by



(V)



(VI)

increase in dielectric constant of the solvent. It does not follow that the maximum at 331·5 mμ ($Me_2N{\cdot}NO$) or 338 mμ ($Et_2N{\cdot}NO$) is necessarily caused by the pure dimer (V or VI; R = Me or Et), since dimerisation is not necessarily complete. The appearance of a clear-cut isosbestic point at 290·5 mμ (ε 10) common to diethylnitrosamine in all the solvents listed in Table 1 is of importance in this connection, since it suggests that the maxima observed when more polar solvents are used are the resultant of two species (a monomer and a dimer) present at the same time in the solution.

The boiling points of dialkylnitrosamines are higher than would be expected from a consideration of their molecular weight and by comparison with alkyl nitrites. Strong dipolar interaction or partial dimerisation would explain this also. If true dimerisation of the type (VI) is responsible for the spectral changes, it can occur to the extent of only a few per cent, since the cryoscopic molecular weight of dimethylnitrosamine in water is the same (±5%) as that of the monomer and as the cryoscopic molecular weight in benzene. This favours the idea of intermolecular dipolar interaction, though it does not completely invalidate the postulate of partial dimerisation to (VI), since *N*-nitroso-dimers (VI) could absorb at shorter wavelength much more intensely than do the monomers at longer wavelength; unpublished results on *C*-nitroso-dimers support this, since their absorption in the 300—320 mμ region is several times as great as for the monomers at longer wavelength (650—680 mμ).

The unexpected behaviour of chloroform could be attributed to hydrogen-bonding of its acidic hydrogen atom to the oxygen atom of the monomeric nitrosamine ($R_2N{-}N{=}O \cdots H{-}CCl_3$). Such hydrogen-bonding [factor (*d*) above] could occur for other solvents and would be in accord with the loss of fine structure of the spectrum. This cannot provide a complete explanation, however, since changes in spectrum are observed with solvents which cannot form hydrogen bonds in this way. Dielectric-constant effects [(*d*) above] may also be involved here, since small changes (2—5 mμ) in the position of an absorption maximum, commonly observed for organic compounds with change from non-polar (light petroleum, CCl_4) to polar solvent (EtOH, etc.), can be interpreted in terms of slight differences in the perturbation introduced by the cage of solvent molecules surrounding the solute molecule. Ham, Rees, and Walsh (*J. Chem. Phys.*, 1952, **20**, 1336) consider that this solvent effect is responsible for the large changes in the spectrum of iodine in various solvents rather than the formation of a 1 : 1 molecular complex (see *J.*, 1953, 2622; 1954, 4145 for references). The ultraviolet absorption of the resonating nitroso-group ($R_2N{\cdot}N{:}O \longleftrightarrow R_2N^{+}{:}N{-}O^{-}$) would certainly be expected to be affected by the dielectric constant of the solvent, but it is difficult to estimate whether this alone could cause shifts of 30 mμ. Apart from chloroform, which would be anomalous on this basis, the changes in spectrum parallel the change in dielectric constant.

Rotational isomerism and/or dipolar interaction or dimerisation and/or solvent effects, with preference for dipolar interaction or true dimerisation, can thus be used to explain the ultraviolet spectra of dialkylnitrosamines. The ultraviolet spectrum of *N*-nitrosobis-2 : 2 : 2-trifluoroethylamine, which differs appreciably from those of the unsubstituted nitrosamines, is in accord with these explanations, and favours the dipolar interaction or true dimerisation concept (*c*). The inductive effect of the strongly electronegative CF_3 groups makes the lone pair of electrons on the nitrogen atom adjacent to the nitroso-group less mobile, and a marked decrease in resonance of the type $R_2N{\cdot}N{:}O \longleftrightarrow R_2N^{+}{:}N{\cdot}O^{-}$ is to be expected. The shift (6 mμ) to longer wavelength of the main peak of *N*-nitrosobis-2 : 2 : 2-trifluoroethylamine relative to that of diethylnitrosamine (Table 1, Fig. 1) reveals

the increase in double-bond character of the nitroso-group; the short-wavelength peak remains unchanged in position and intensity (230 mμ, ε 5000), as expected. The spectrum of *N*-nitrosobis-2 : 2 : 2-trifluoroethylamine is only slightly changed by polar solvents such as ethanol, dioxan, acetonitrile, or water (Fig. 1), in marked contrast to the spectra of the unsubstituted dialkylnitrosamines [cf. the shift of 6 mμ for an aqueous solution with the 30 mμ shift observed for dimethylnitrosamine], and increase in dielectric constant merely causes loss of the flanking peaks (Fig. 1). This supports the concepts of dipolar interaction or true dimerisation in dialkylnitrosamines, since increase in the electron-attracting power of R (*e.g.*, R = $CF_3 \cdot CH_2$) should prevent or at least considerably reduce such effects, just as it does with *C*-nitroso-compounds (*e.g.*, $CF_3 \cdot NO$ is completely monomeric whereas Ph·NO or $CMe_3 \cdot NO$ are mainly dimeric; *J.*, 1953, 2075; 1954, 696, 912, 919). Rotational isomerism should similarly be diminished, since stabilisation of a form analogous to (I) by hydrogen-bonding would be reduced (cf. hydrogen-bonding in the fluoro-alcohols, *J.*, 1953, 1757). Hydrogen-bonding involving solvent would also decrease, and the nitroso-group would be less sensitive to changes in dielectric constant.

(b) *Infrared spectra.* In Part VI (*loc. cit.*) it was shown that the infrared spectra of *liquid* dialkylnitrosamines have no strong band in the usual N:O stretching vibration region, but that three bands characterise the spectra: a band at 7·1—7·4 μ, a very strong band at 7·6—8·6 μ, and a strong band *ca.* 9·5 μ. The first of these was tentatively assigned to the N:O stretching vibration, and the last to the N–N stretching vibration.* Evidence is now given which shows that the N:O assignment must be modified.

The infrared spectrum of liquid dimethylnitrosamine between 5·5 and 8·0 μ shows four strong bands at 6·92, 7·10, 7·60, and 7·76 μ of approximately equal intensity (Fig. 2, I; C.S. 75 †), and the absence of a strong band between 5·8 and 6·8 μ is particularly noteworthy. Dimerisation of the nitrosamine to give (VI; R = Me), which would explain the absence of the N:O vibration from its expected position, was suggested in Part VI (*loc. cit.*), but rejected since a solution of dimethylnitrosamine in chloroform (Fig. 2, III) failed to show any change in the positions or relative intensities of the bands; change in the monomer : dimer ratio, with consequent change in spectrum, was to have been expected in a solvent of such low dielectric constant. The ultraviolet spectroscopic study discussed above subsequently made it necessary to study the effect of solvent on the infrared spectrum of dimethylnitrosamine.

The spectrum of a solution of dimethylnitrosamine in carbon tetrachloride shows distinct changes in several bands (Fig. 2, IV); the 6·92 μ band moves to 6·88 μ, but relative to the 7·76 μ band scarcely changes in intensity, and the 7·10 and 7·60 μ bands appear at 7·10 and 7·63 μ respectively and are appreciably weakened relative to the 7·76 μ band. The 9·53 μ (N–N) band shifts to 9·65 μ without change in intensity, but the 11·83 and 14·65 μ bands which appear in the pure liquid remain unchanged in both chloroform and carbon tetrachloride solutions. The spectrum of liquid dimethylnitrosamine at 100° is much like that of the liquid at 25° but there is a distinct, though small, decrease in the intensities of the 7·10 and the 7·60 μ band. Finally the spectrum of dimethylnitrosamine vapour at 120° (Fig. 2, II; C.S. 230 †) shows the 7·60 μ band as only a weak shoulder and the 7·1 μ band as a weak peak; the strong bands of the spectrum are now at 6·72, 7·75, and 9·85 μ. The 6·72 μ band is thus assigned to the N:O stretching vibration in monomeric dimethylnitrosamine containing a " free " nitroso-group [*i.e.*, one unaffected by bonding as in (I), dipolar interaction as in (V), or dimerisation as in (VI)] and the 9·85 μ band to the N–N stretching vibration. Dipolar interaction, dimerisation, solvent effects, and other interactions are negligible in the vapour phase, and strong interactions in liquid nitrosamines are thus revealed by infrared spectra as well as by ultraviolet spectra. The 6·92 and 7·60 μ bands in the spectrum of liquid dimethylnitrosamine (Fig. 2, I), which are shifted and decreased

* We take this opportunity of correcting a typographical error in Part VI which was carried through to other papers (*J.*, 1954, 697, 919), namely, that the nitrogen–nitrogen vibration appeared in print as N–O instead of N–N.

† Spectra so marked have been deposited with the Chemical Society. Photocopies, price 3*s.* 0*d.* per copy per spectrum, may be obtained on application, quoting the C.S. number to the General Secretary, the Chemical Society, Burlington House, Piccadilly, London, W.1.

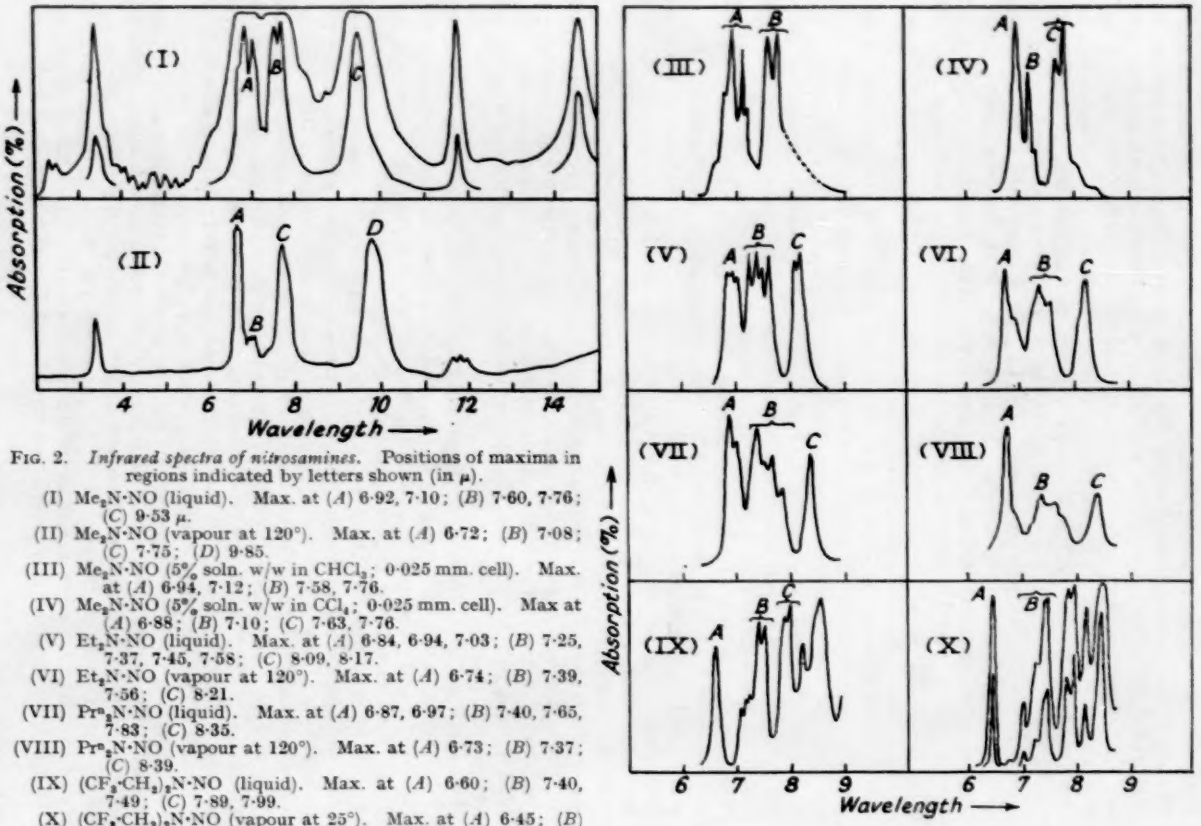


FIG. 2. *Infrared spectra of nitrosamines.* Positions of maxima in regions indicated by letters shown (in μ).

(I) $Me_2N{\cdot}NO$ (liquid). Max. at (*A*) 6·92, 7·10; (*B*) 7·60, 7·76; (*C*) 9·53 μ.

(II) $Me_2N{\cdot}NO$ (vapour at 120°). Max. at (*A*) 6·72; (*B*) 7·08; (*C*) 7·75; (*D*) 9·85.

(III) $Me_2N{\cdot}NO$ (5% soln. w/w in $CHCl_3$; 0·025 mm. cell). Max. at (*A*) 6·94, 7·12; (*B*) 7·58, 7·76.

(IV) $Me_2N{\cdot}NO$ (5% soln. w/w in CCl_4; 0·025 mm. cell). Max at (*A*) 6·88; (*B*) 7·10; (*C*) 7·63, 7·76.

(V) $Et_2N{\cdot}NO$ (liquid). Max. at (*A*) 6·84, 6·94, 7·03; (*B*) 7·25, 7·37, 7·45, 7·58; (*C*) 8·09, 8·17.

(VI) $Et_2N{\cdot}NO$ (vapour at 120°). Max. at (*A*) 6·74; (*B*) 7·39, 7·56; (*C*) 8·21.

(VII) $Pr^n_2N{\cdot}NO$ (liquid). Max. at (*A*) 6·87, 6·97; (*B*) 7·40, 7·65, 7·83; (*C*) 8·35.

(VIII) $Pr^n_2N{\cdot}NO$ (vapour at 120°). Max. at (*A*) 6·73; (*B*) 7·37; (*C*) 8·39.

(IX) $(CF_2{\cdot}CH_2)_2N{\cdot}NO$ (liquid). Max. at (*A*) 6·60; (*B*) 7·40, 7·49; (*C*) 7·89, 7·99.

(X) $(CF_2{\cdot}CH_2)_2N{\cdot}NO$ (vapour at 25°). Max. at (*A*) 6·45; (*B*) 7·02, 7·25, 7·46.

in intensity respectively for a carbon tetrachloride solution, are assigned to either (i) the N:O stretching vibrations in the liquid monomer [possibly bonded as in (I)] and dimer (V or VI; R = Me) respectively, or (ii) to the N:O stretching vibrations in the rotational isomers (II) and (I) respectively. Hydrogen bonding as in (I) would make this isomer the more stable and the N:O vibration would appear at the longer wavelength.

In carbon tetrachloride solution the 6·92 μ band appears at 6·88 μ, not at 6·72 μ, the position for the stretching vibration of the " free " nitroso-group of the vapour. As the solution of dimethylnitrosamine in carbon tetrachloride is progressively diluted, a weak absorption appears at 6·73 μ but there is no major change in the spectrum. The 7·60 μ band is at 7·63 μ in the carbon tetrachloride solution and appreciably weakened (Fig. 2, IV); it decreases slightly in intensity relative to the 7·76 μ band on further dilution, but does not disappear, thus revealing the powerful nature of the interactions in the nitrosamines. The 6·88 and 7·63 μ bands are assigned as for the 6·92 and 7·60 μ bands of the liquid.

The decrease in the extent of dipolar interaction or true dimerisation, or of rotational isomerism on dissolution in carbon tetrachloride, is as expected, but the absence of change in spectrum for a chloroform solution is unexpected, and must be explained, as must the anomalous ultraviolet spectrum in chloroform, on the basis that chloroform is sufficiently polar to fail to change the monomer : dimer (V or VI) or rotational isomer ratio in the liquid nitrosamine, or that additional hydrogen bonding to the nitroso-group through the acidic hydrogen of chloroform becomes possible.

It will be noted that a major change in the infrared spectrum of dimethylnitrosamine is brought about by change from vapour to solution, even in a non-polar solvent such as carbon tetrachloride. This suggests that solvent effects of the type discussed for the ultraviolet spectra cannot play a major part in the spectral changes, but that dipolar interaction (V), dimerisation (VI), or rotational isomerism in the nitrosamine itself, or a combination of the three is responsible, particularly since major changes are observed in both infrared and ultraviolet spectra of films of the liquid nitrosamine. Dipolar interaction and true dimerisation, particularly the former, are the most probable major factors able to cause such profound changes in infrared spectra, and it is thus concluded that a monomer $\rightleftharpoons$ dimer (V or VI) equilibrium is present in liquid dimethylnitrosamine and its solutions in various solvents. It is possible that rotational isomerism and solvent effects play a minor part.

The infrared spectra of diethyl- and di-*n*-propyl-nitrosamine have also been studied in more detail, and show similar, though less marked, effects summarised in Table 2, where data for *C*-nitroso-compounds are also given.

TABLE 2. N:O *vibration in* N- *and* C-*nitroso-compounds.*[1]

	Vapour :	Solution in CCl_4 :		Liquid :	
	monomer	monomer	dimer	monomer	dimer
$Me_2N{\cdot}NO$	6·72	6·88	7·63	6·92	7·60
$Et_2N{\cdot}NO$	6·74	6·84	?	6·93	?
$Pr^n_2N{\cdot}NO$	6·73	6·85 [3]	?	6·87	?
$(CF_3{\cdot}CH_2)_2N{\cdot}NO$ ...	6·45	6·54	Nil	6·60	Nil
$Me_2C{\cdot}NO$ [2]	—	6·46	7·34	—	—
$Ph{\cdot}NO$ [2]	—	6·61	7·19	—	—
$CF_3{\cdot}NO$ [2]	6·25	—	—	—	—
$C_2F_5{\cdot}NO$	6·24	—	—	—	—
$C_3F_7{\cdot}NO$	6·23	—	—	—	—

[1] This replaces part of the Table given in *J.*, 1954, 912. [2] Haszeldine and Jander, *J.*, 1954, 912. [3] A band appears at this position in the spectra of the longer-chain nitrosamines given in Part VI, but the possibility of CH_2 vibrations' appearing in this region makes assignment of the band to the N:O group open to doubt.

Diethylnitrosamine shows a strong band at 6·74 μ in the vapour (Fig. 2, VI; C.S. 231) clearly assigned to the " free " N:O stretching vibration (Table 2). The liquid nitrosamine fails to show a band in this region (Fig. 2, V; C.S. 76) and by analogy with dimethylnitrosamine the band at 6·84 μ can be assigned to the N:O vibration of monomeric diethylnitrosamine in a monomer $\rightleftharpoons$ dimer (V or VI) equilibrium. Unlike dimethylnitrosamine, however, the solution in carbon tetrachloride is identical with that of the liquid nitrosamine,

and changes in the relative intensities of the bands cannot be detected even on dilution; the N:O vibration for the dimer (V or VI) (or rotational isomer) thus cannot be assigned with certainty. Interaction in the liquid must thus be particularly strong for diethylnitrosamine, and for di-*n*-propylnitrosamine which shows a similar effect (Vapour: Fig. 2, VIII; C.S. 232. Liquid: Fig. 2, VII, C.S. 77; CCl_4 solution identical with Fig. 2*g*). The infrared spectrum of liquid di-*n*-pentyl- and di-*n*-hexyl-nitrosamine and of nitrosopiperidine which were also described in Part VI (*loc. cit.*) can be interpreted similarly.

N-Nitrosobis-2 : 2 : 2-trifluoroethylamine shows N:O stretching vibration at 6·45 μ for the vapour (Fig. 2, **X**; C.S. 233) and this shifts to only 6·54 μ for a carbon tetrachloride solution, and to 6·60 μ for the liquid (Fig. 2, IX; C.S. 234). Dimerisation, rotational isomerism, or solvent effects are thus much reduced in this nitrosamine, and the infrared data, which are in accord with the ultraviolet data reported above, support the explanations as dipolar interaction or dimerisation in particular. That the strong doublet in the infrared spectrum of *N*-nitrosobis-2 : 2 : 2-trifluoroethylamine at 7·89, 7·99 μ (liquid) and 7·89, 8·00 μ (carbon tetrachloride solution) is not caused by the N:O vibration of the dimeric nitrosamine is shown by the fact that it remains in the vapour (7·81, 7·95 μ). The rest of the spectrum of the nitrosamine in carbon tetrachloride solution is almost identical with that of the vapour, again showing the negligible interaction for this nitrosamine. The N–N vibration in particular shows only slight change, whereas the N–N vibration for unsubstituted nitrosamines changes with the N:O vibration (Table 3) as expected.

TABLE 3. N–N *vibration in nitrosamines.*

	Liquid	CCl_4 soln.	Vapour		Liquid	CCl_4 soln.	Vapour
$Me_2N{\cdot}NO$	9·53	9·60	9·85	$(C_5H_{11})_2N{\cdot}NO$	9·22	9·24	—
$Et_2N{\cdot}NO$	9·35	9·41	9·55	$(C_6H_{13})_2N{\cdot}NO$	9·18	9·21	—
$Pr^n_2N{\cdot}NO$	9·35	9·37	9·53	$(CF_3{\cdot}CH_2)_2N{\cdot}NO$ ...	9·50	9·57	9·56

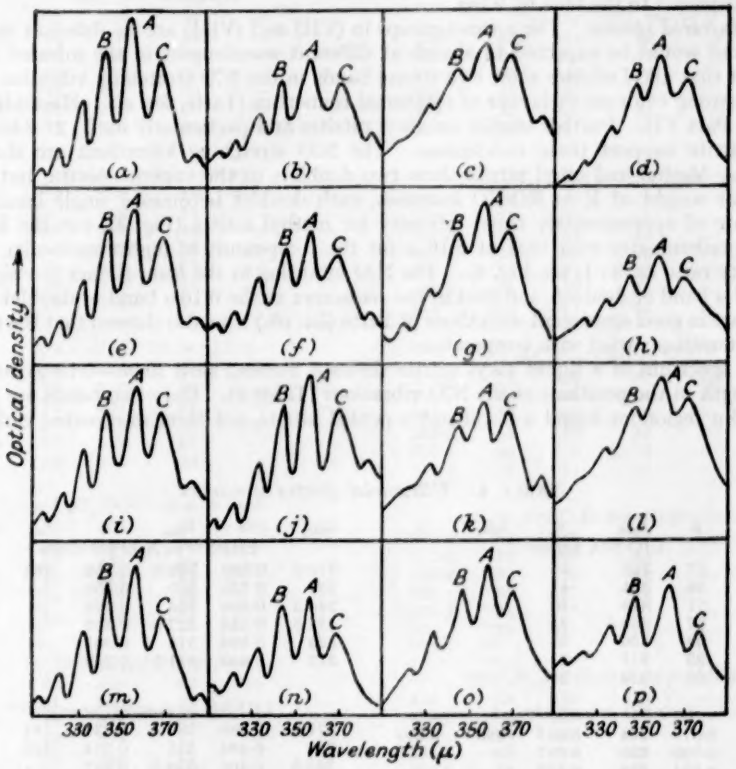
Nitrites.—(a) *Ultraviolet spectra.* The ultraviolet spectra of alkyl nitrites resemble those of *C*-nitroso-compounds and are substantially independent of R in RO·NO; they are identical in light petroleum and in ethanol, and can thus be distinguished from those of nitrosamines (Part VI, *loc. cit.*). Spectra of ethanolic solutions were recorded under conditions (10—12°; sealed cells) such that loss of ethyl nitrite (b. p. 17°) formed by the equilibrium $RO{\cdot}NO + EtOH \rightleftharpoons ROH + EtO{\cdot}NO$ was prevented; this is important, since complete conversion into ethyl nitrite would otherwise occur. The equilibrium lies well to the left, with not more than 10—20% of ethyl nitrite in the solution when R = Bu^n or *n*-pentyl (unpublished results), and the spectrum of an ethanolic solution of an alkyl nitrite is thus predominantly that of the alkyl nitrite and not that of ethyl nitrite. To avoid the necessity of recording spectra at low temperatures with sealed cells, and for use with nitrites where the equilibrium constant for the reaction with ethyl alcohol is not known, other polar solvents, where equilibria of the above type are not possible, can be used for distinguishing nitrites from nitrosamines. Thus, the alcohol ROH can be used as solvent for the nitrite RO·NO (*e.g.*, Bu^nOH for $Bu^nO{\cdot}NO$) or, for more general application, the polar solvents acetonitrile or dimethylformamide. Table 4 shows that the positions of the maxima in the spectrum of a nitrite in these solvents, and also in chloroform, are virtually the same as in light petroleum solutions. By contrast, the spectrum of a nitrosamine is markedly affected by change of solvent (Table 1).

Rotational isomerism is possible in nitrites, with a planar *cis*-form (VII), possibly stabilised by hydrogen-bonding, and a planar *trans*-form (VIII). Tarte (*J. Chem. Phys.*, 1952, **20**, 1570; *Bull. Soc. chim. Belg.*, 1950, **59**, 365; 1953, **62**, 401) provided good evidence for this from the infrared and ultraviolet spectra of alkyl nitrites and nitrous acid, particularly by change in spectra with increase in temperature; the *trans*-isomer (VIII) was believed to predominate at higher temperatures. Wagner (*Acta Phys. Austriaca*, 1953, **8**, 175) interpreted the Raman spectrum of methyl nitrite in terms of an intramolecularly hydrogen-bonded *cis*-form in which the hydrogen bond was broken with increase in temperature.

Change of solvent might be expected to change the *cis* : *trans* ratio at any given

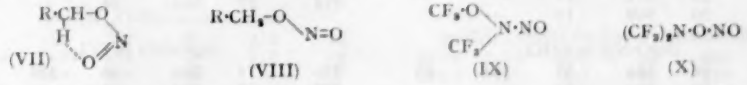
temperature, and the results in Table 4 shows that this is so. The ultraviolet spectrum of *n*-butyl nitrite is identical for the vapour, for the liquid, and for solutions in carbon tetrachloride, chloroform, or light petroleum, not only as regards positions of the maxima, but also as regards the relative heights of the maxima. In particular, peak *C* remains smaller than peak *B*, where *B* and *C* flank the main peak *A* (Fig. 3). Change of solvent to acetonitrile or dimethylformamide causes negligible change in wavelength of the peaks, but the

FIG. 3. *Ultraviolet spectra of nitrites.*



n-Butyl nitrite: (*a*) vapour; (*b*) in light petroleum; (*c*) in acetonitrile; (*d*) in dimethylformamide.
n-Pentyl nitrite: (*e*) vapour; (*f*) in light petroleum; (*g*) in acetonitrile; (*h*) in dimethylformamide.
*iso*Pentyl nitrite: (*i*) vapour; (*j*) in light petroleum; (*k*) in acetonitrile; (*l*) in dimethylformamide.
Ethyl nitrite: (*m*) vapour; (*n*) in light petroleum; (*o*) in acetonitrile.
2 : 2 : 2-Trifluoroethyl nitrite: (*p*) vapour.

relative heights of *B* and *C* are changed, with *C* now higher than *B* (Fig. 3). *n*-Pentyl nitrite shows a similar though less pronounced effect (Fig. 3) in which peak *C* becomes equal to or slightly more intense than peak B. *iso*Pentyl nitrite also shows reversal in the



relative intensities of peaks *B* and *C* on change from a non-polar to a polar solvent (Table 4, Fig. 3). The change is less marked with ethyl nitrite, but peak *C* approaches peak *B* in intensity.

This change in relative peak heights without appreciable change in wavelength can be interpreted as change in the *cis–trans* ratio.

The spectrum of 2 : 2 : 2-trifluoroethyl nitrite vapour shows the main peak at 364 mμ, *i.e.*, a shift of 9 mμ to the blue relative to ethyl nitrite (Table 4), caused by the increased double-bond character of the nitroso-group due to fluorine. The ratio of the peak heights also differs from that for the alkyl nitrites, since peak *C* is much lower than peak *B* (Fig. 3). Since the infrared spectrum shows that 2 : 2 : 2-trifluoroethyl nitrite is mainly the *trans*-isomer, the ultraviolet spectrum of this compound can be taken as that of a typical *trans*-nitrite displaced to the blue by 9 mμ.

(b) *Infrared spectra.* The nitroso-groups in (VII) and (VIII) are in different environments and would be expected to absorb at different wavelengths in the infrared region. The fact that alkyl nitrites show two strong bands in the N:O stretching vibration region (6 μ) is strong evidence in favour of rotational isomerism (Tarte, *loc. cit.*; Haszeldine and Jander, Part VI). Further studies on alkyl nitrites and particularly on 2 : 2 : 2-trifluoroethyl nitrite support these conclusions. The N:O stretching vibrations are shown in Table 5. Methyl and ethyl nitrite show two doublets in the vapour spectra, but as the molecular weight of R in RO·NO increases, each doublet becomes a single band. The bands are of approximately equal intensity for methyl nitrite (Fig. 4), but the band at 5·97 μ predominates over that at 6·16 μ for the compounds of higher molecular weight (intensity ratio *ca.* 3 : 1, see Fig. 4). The N:O vibration in the *trans*-isomer is assigned to the 5·97 μ band or doublet, and that in the *cis*-isomer to the 6·16 μ band or doublet; these results are in good agreement with those of Tarte (*loc. cit.*) who also showed that the relative band intensities varied with temperature.

The spectrum of a liquid alkyl nitrite shows a marked shift (0·05—0·10 μ) to longer wavelength in the positions of the N:O vibrations (Table 5). Only two bands are present in the 6 μ region for liquid *n*-butyl and *n*-pentyl nitrite, not three as reported earlier (*J.*,

TABLE 4. *Ultraviolet spectra of nitrites.*

$\lambda_{max.}$	ε	$\lambda_{min.}$	ε	$\lambda_{infl.}$	ε	$\lambda_{max.}$	ε	$\lambda_{min.}$	ε	$\lambda_{infl.}$	ε
		EtO·NO, *vapour*						EtO·NO *in light petroleum* [1]			
384	27	382	26	—	—	370·5	0·599	364·5	0·456	385	0·274
369	56	364	41	—	—	357	0·758	350	0·450	—	—
355	71	349	40	—	—	344·5	0·698	338	0·368	—	—
343	67	336·5	31	—	—	333·5	0·538	327·5	0·309	—	—
332	50	326	24	—	—	323	0·394	318	0·301	—	—
321·5	33	317	21	—	—	313	0·350	311·5	0·347	—	—
312·5	25	309	21	—	—						
		EtO·NO *in acetonitrile* [1]						EtO·NO *in dimethylformamide* [1]			
369·5	0·579	364	0·515	385	0·288	371·5	0·390	365·5	0·331	384	0·190
357	0·700	350	0·517	—	—	358	0·464	351	0·324	315	0·136
345	0·624	338	0·426	—	—	345·5	0·406	338·5	0·252	—	—
333·5	0·475	327	0·340	—	—	334·5	0·292	328	0·183	—	—
323·5	0·358	317	0·297	—	—	325	0·193	310·5	0·125	—	—
313	0·303	311	0·298	—	—						
		$Bu^nO·NO$, *vapour*						$Bu^nO·NO$ *in light petroleum*			
384	23	380	21	—	—	384	35	382	35	—	—
369	46	363	32	—	—	370	75	365	54	—	—
355	57	349	31	—	—	357	92	350	49	—	—
343	50	337	24	—	—	345	81	338	38	—	—
332	37	327	19	—	—	333	58	327	28	—	—
322	26	317	17	—	—	323	37	318	24	—	—
313	20	309	18	—	—	314	27	310	24	—	—
		$Bu^nO·NO$ *in* $CHCl_3$						$Bu^nO·NO$ *in* CCl_4			
369·5	66	364	57	384	33	370	74	364	56	384	35
357	80	350	53	—	—	357	89	350	54	—	—
345	68	338	40	—	—	345	77	338	41	—	—
334	48	327	27	—	—	334	55	327	30	—	—
323	30	317	20	—	—	323·5	36	317	24	—	—
314	21	310	19	—	—	314	26	310	24	—	—

TABLE 4. (*Continued.*)

$\lambda_{max.}$	ε	$\lambda_{min.}$	ε	$\lambda_{infl.}$	ε
		$Bu^nO{\cdot}NO$ *in acetonitrile*			
385	34	381	32	325	26
370·5	65	364	50	315	19
357	70	350	49	—	—
345	57	337	37	—	—
333·5	40	310	18	—	—
		$Bu^nO{\cdot}NO$ *in* Bu^nOH			
383	31	382	31	—	—
370	65	364	49	—	—
357	79	350	46	—	—
345	68	338	35	—	—
333·5	48	327	25	—	—
323·5	31	318	20	—	—
314	22	310	21	—	—
		$n\text{-}C_5H_{11}O{\cdot}NO$, *vapour*			
384	19	380	18	—	—
369	38	364	26	—	—
355	45	349	25	—	—
343	40	337	19	—	—
332	30	326	16	—	—
321	20	317	14	—	—
313	16	310	15	—	—
		$n\text{-}C_5H_{11}O{\cdot}NO$ *in* $CHCl_3$			
369·5	69	363	59	384	35
357	81	350	55	—	—
344·5	70	337	41	—	—
333·5	49	326	29	—	—
323·5	32	317	23	—	—
315	24	312	23	—	—
		$n\text{-}C_5H_{11}O{\cdot}NO$ *in acetonitrile*			
369·5	60	364	51	384	31
357	70	350	50	—	—
345	59	337	39	—	—
333·5	42	326	28	—	—
323·5	29	317	23	—	—
314	24	312	24	—	—
		iso-$C_5H_{11}O{\cdot}NO$, *vapour*			
384	24	380	22	—	—
369	41	363	29	—	—
355·5	48	349	27	—	—
343	42	336	22	—	—
332	32	326	18	—	—
321·5	23	317	16	—	—
313	18	309	17	—	—
		iso-$C_5H_{11}O{\cdot}NO$ *in* $CHCl_3$			
370	60	364	51	385	28
357	71	350	48	—	—
345	61	337·5	35	—	—
333·5	43	327	25	—	—
323·5	27	317·5	18	—	—
314	19	310	17	—	—
		iso-$C_5H_{11}O{\cdot}NO$ *in acetonitrile*			
386	28	382	25	324	21
370·5	53	364	40	315	16
357	58	350	40	—	—
345·5	47	338	31	—	—
335	33	310	15	—	—

$\lambda_{max.}$	ε	$\lambda_{min.}$	ε	$\lambda_{infl.}$	ε
		$Bu^nO{\cdot}NO$ *in dimethylformamide*			
371	65	365	54	386	33
357·5	75	351	54	—	—
345·5	63	339	41	—	—
334·5	45	327	30	—	—
325	31	318	24	—	—
316	24	311	24	—	—
		$CF_3{\cdot}CH_2{\cdot}O{\cdot}NO$, *vapour* [2]			
379·5	42	373	19	—	—
364	64	357	34	—	—
349·5	60	343	32	—	—
337	44	330	26	—	—
325	30	318	22	—	—
315	23	311	22	—	—
		$n\text{-}C_5H_{11}O{\cdot}NO$ *in light petroleum*			
384	34	383	33	—	—
370·5	71	364	51	—	—
356·5	85	350	48	—	—
344·5	75	338	36	—	—
333·5	54	327	27	—	—
323	35	317	23	—	—
314	26	311	24	—	—
		$n\text{-}C_5H_{11}O{\cdot}NO$ *in* CCl_4			
370·5	74	364	57	384	35
357	88	350	54	—	—
345	76	337	40	—	—
333·5	54	326	30	—	—
323·5	35	318	24	—	—
314	27	311	25	—	—
		$n\text{-}C_5H_{11}O{\cdot}NO$ *in dimethylformamide*			
370·5	67	365	57	385	33
357·5	79	351	56	—	—
345·5	69	338	44	—	—
335	50	327	33	—	—
324·5	35	317	26	—	—
315	26	311	25	—	—
		iso-$C_5H_{11}O{\cdot}NO$ *in light petroleum*			
385	30	382	29	—	—
370·5	64	364	46	—	—
357	78	350	43	—	—
344·5	69	338	33	—	—
333·5	49	327	24	—	—
323·5	32	317	21	—	—
314	24	310	21	—	—
		iso-$C_5H_{11}O{\cdot}NO$ *in* CCl_4			
370·5	68	364	52	384	33
357	82	350	49	—	—
344·5	71	338	38	—	—
333·5	51	327	28	—	—
323·5	33	318	23	—	—
314	25	311	24	—	—
		iso-$C_5H_{11}O{\cdot}NO$ *in dimethylformamide*			
371·5	50	365	43	385	26
358·5	57	352	42	326	22
346	48	338	32	316	16
335	34	310	15	—	—

[1] Optical densities given instead of ε, since compound is too volatile to be weighed quantitatively for solution work. [2] Also max. at 221 mμ, ε 900.

1954, 691); the 5·75 μ band, which was caused by decomposition on exposure to infrared radiation, should be deleted from C.S. spectra 73 and 74. There is a slight change in intensity ratio of the 6 μ bands relative to the vapour spectra. The dipolar interaction causing the shift in the infrared spectrum is not changed by dissolving the nitrite in a non-polar solvent such as carbon tetrachloride, since the infrared bands appear at the same position (Table 5); there is a slight change in intensity ratio, with increase in the 6·22 μ band, however, and this is again consistent with rotational isomerism.

The infrared spectrum of 2 : 2 : 2-trifluoroethyl nitrite vapour shows a strong sharp peak at 5·76 μ which is assigned to the N:O stretching vibration of the *trans*-isomer (VIII;

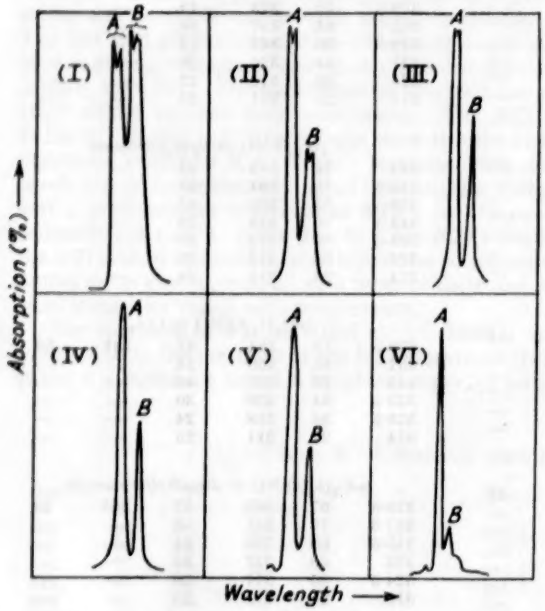


FIG. 4. *Infrared spectra of nitrites in the vapour phase.* Positions of maxima in regions indicated by letters shown (in μ).

(I) MeO·NO. Max. at (*A*) 5·91, 5·98; (*B*) 6·13, 6·17.
(II) EtO·NO. Max. at (*A*) 5·94, 5·99; (*B*) 6·14, 6·17.
(III) Bu^{n}O·NO. Max. at (*A*) 5·96, 5·98; (*B*) 6·17.
(IV) *n*-C_5H_{11}·O·NO. Max. at (*A*) 5·97; (*B*) 6·16.
(V) *iso*-C_5H_{11}·O·NO. Max. at (*A*) 5·97; (*B*) 6·16.
(VI) CF_3·CH_2·O·NO. Max. at (*A*) 5·76; (*B*) 5·90.

R = CF_3). The *cis*-isomer is present at much lower concentration (5·90 μ band; ratio of intensities 9 : 1) than in ethyl nitrite. The shift of the N:O vibration to shorter wavelength is in accord with similar shifts observed in C:O vibrations on replacement of hydrogen by

TABLE 5. N:O *vibrations in alkyl nitrites.*

Compound	State	C.S. no.	*trans*-Isomer (VIII)	*cis*-Isomer (VII)	Overtones
MeO·NO	Vapour	235	5·91, 5·98 (d)	6·13, 6·17 (d)	3·00, 3·10
EtO·NO	Vapour	236	5·94, 5·99 (d)	6·14, 6·17 (d)	3·03, 3·13
	CCl_4	—	6·05	6·20	—
Bu^{n}O·NO	Vapour	237	5·96, 5·98 (d)	6·17	3·03, 3·14
	Liquid	73	6·07	6·22	3·09, 3·15
	CCl_4	—	6·06	6·22	—
n-C_5H_{11}O·NO	Vapour	238	5·97	6·16	3·02, 3·13
	Liquid	239	6·06	6·21	3·07, 3·16
	CCl_4	—	6·05	6·21	—
iso-C_5H_{11}O·NO	Vapour	240	5·97	6·16	3·02, 3·13
	Liquid	241	6·05	6·21	3·07, 3·15
	CCl_4	—	6·05	6·22	—
CF_3·CH_2·O·NO	Vapour	242	5·76	5·90	2·92
	Liquid	—	5·80	—	—
	CCl_4	—	5·80	5·92	

d = doublet. CCl_4 indicates CCl_4 solution.

fluorine in organic molecules (Haszeldine, *Nature*, 1951, **168**, 1028) and with the ultraviolet spectrum of the compound. The marked increase in the *trans* : *cis* ratio is also as expected in view of the decreased basicity of the oxygen atoms, and strongly supports the rotational-isomerism postulate and the assignment of the 5·97 μ band in unsubstituted alkyl nitrites to the *trans*-isomer. The relatively slight shift of the N:O vibration on change from vapour to liquid or solution (Table 5) is also in accord with this.

(3) *Trifluoronitrosomethane Dimer.*—Trifluoronitrosomethane was shown earlier (*J.*, 1954, 696) to dimerise to an orange gas which could be (IX) or (X), and from the spectroscopic studies reported in Part VI (*loc. cit.*) it was concluded that (IX) was slightly the more probable : the infrared spectrum resembled that of a nitrosamine rather than that of a nitrite. It was pointed out that final identification must await detailed chemical investigation in a field where there are at present no established reference compounds. In the present paper it is shown that the " free " nitroso-group in a nitrosamine vapour absorbs at 6·72 μ and the absorption is shifted by introduction of fluorine into the alkyl groups to 6·45 μ [$(CF_3 \cdot CH_2)_2N \cdot NO$]; it is thus now likely that the N:O vibration for the vapour of (IX) would lie between 5·9 and 6·4 μ, but the spectrum of trifluoronitrosomethane dimer (C.S. 81) shows only weak absorption in this region. The studies on alkyl nitrites reported above show that the *trans*-isomer absorbs at 5·97 μ and that trifluoroethyl nitrite absorbs at 5·76 μ. The N:O vibration for (X) would thus be expected to lie between 5·4 and 5·7 μ. The spectrum of trifluoronitrosomethane dimer in fact shows a strong doublet at 5·47, 5·55 μ and this can now be assigned to the N:O vibration.

The new spectroscopic studies on nitrosamines and nitrites thus no longer enable (IX) to be favoured over (X), but the reverse. A full chemical investigation, which also shows that trifluoronitrosomethane dimer is (X) and not (IX), will be reported later.

Experimental

The alkyl nitrites and nitrosamines were taken from the same samples as used in Part VI. Methyl and ethyl nitrite were prepared from the alcohols in the usual way and purified by distillation *in vacuo*.

N-*Nitrosobis*-2 : 2 : 2-*trifluoroethylamine.*—Bis-2 : 2 : 2-trifluoroethylamine, kindly presented by Professor G. F. Wright, was redistilled (b. p. 82°), then added (1·00 g.) to a 20-ml. flask. Concentrated hydrochloric acid (0·6 ml.) was added and the white solid formed was stirred and heated (70°) during the addition (1 hr.) of aqueous sodium nitrite (0·6 g. in 1 ml. of water). The mixture was stirred for 1 hr., then cooled, and the lower oily layer was dried (P_2O_5) and distilled, giving N-*nitrosobis*-2 : 2 : 2-*trifluoroethylamine* (0·83 g., 72%), b. p. 114—115°, n_D^{18} 1·3374 (Found : C, 23·2; H, 2·1; N, 13·2. $C_4H_4ON_2F_6$ requires C, 22·9; H, 1·9; N, 13·3%).

2 : 2 : 2-*Trifluoroethyl Nitrite.*—Trifluoroethanol (23·9 g.), sodium nitrite (20·6 g.), and water (40 ml.) were shaken in a 250-ml. flask connected *via* a reflux condenser to a trap cooled in liquid oxygen, whilst concentrated hydrochloric acid (25·8 ml.) in water (25 ml.) was dropped in. The volatile products were fractionated *in vacuo*, to give dinitrogen tetroxide, nitric oxide, and crude trifluoroethyl nitrite. The last fraction was shaken with mercury (2 hr.) in a sealed tube to remove traces of dinitrogen tetroxide, then refractionated to give 2 : 2 : 2-*trifluoroethyl nitrite* (8·1 g., 27%), b. p. 15·8° (Found : C, 18·4; H, 1·4; N, 10·6%; *M*, 128. $C_2H_2O_2NF_3$ requires C, 18·6; H, 1·6; N, 10·9%; *M*, 129) as a pale greenish-yellow gas.

Ultraviolet Spectra.—A Unicam spectrophotometer was used. Solvents were anhydrous, redistilled, and showed little absorption in the regions studied. The spectra of liquid nitrosamines were taken with a thin film pressed between two silica discs.

Infrared Spectra.—A Perkin–Elmer Model 21 Spectrophotometer with rock-salt optics was used. The spectrum of liquid 2 : 2 : 2-trifluoroethyl nitrite was obtained by cooling the cell used to 4° and adding the cooled nitrite as liquid. The spectrum could be recorded before the temperature of the cell reached the b. p. of the nitrite.

We thank Professor G. F. Wright for a sample of bis-2 : 2 : 2-trifluoroethylamine.

University Chemical Laboratory, Cambridge. [*Received, May 18th*, 1955.]

*Kinetic Studies of the Oxidation of Aromatic Compounds by Potassium Permanganate. Part IV.** n- *and* iso-*Propylbenzene.*

By C. F. Cullis and J. W. Ladbury.

[Reprint Order No. 6306.]

The kinetics of the oxidation by potassium permanganate of *n*- and *iso*-propylbenzene have been investigated and compared with those of the lower homologues. With both isomers, analysis of oxidation products shows that initial attack occurs at the α-carbon atom. *n*-Propylbenzene yields propiophenone, which is rapidly further oxidised to benzoic and acetic acid; *iso*propylbenzene gives acetophenone which is slowly converted into benzoic acid and carbon dioxide. Practically all the carbon dioxide evolved arises from attack of the β- and γ-carbon atoms of the alkyl chain, and not from disruption of the aromatic ring.

The effect of added salts shows that the importance of intermediate manganese ions as oxidising entities depends on whether the group adjacent to the aromatic ring is primary, secondary, or tertiary; susceptibility to direct attack by permanganate, and overall reactivity, both increase in the order, $CH < CH_2 < CH_3$.

Earlier studies of the oxidation of some monoalkylbenzenes (Parts I—III, *J.*, 1955, 555, 1407, 2850) have been extended to *n*- and *iso*-propylbenzene.

Experimental

The experimental methods were similar to those described in Part I (*loc. cit.*). The solvent was 54·2% w/v aqueous acetic acid.

Products of the Oxidation.—Ether extracts containing the neutral and acidic constituents were obtained by a method similar to that outlined in Part I.

(a) n-*Propylbenzene.* The ether and unchanged *n*-propylbenzene were distilled from the neutral extract. The residue contained a small amount of propiophenone (m. p. of 2 : 4-dinitrophenylhydrazone 188°; lit., 188°); no alcohols could be detected and the iodoform test for the acetyl group was negative.

Some ether was distilled from the extract containing the acid constituents, and on further concentration a large yield of benzoic acid (m. p. 121°; lit., 121°) was obtained. No evidence was found for the presence of ketonic acids or phenols.

Since the only detectable products are propiophenone (in very small yield) and benzoic acid, it appears that oxidation takes place initially at the α-carbon atom to give propiophenone, which is rapidly further oxidised to benzoic acid.

(b) iso*Propylbenzene.* After the ether and unchanged *iso*propylbenzene had been removed from the neutral extract, the remainder distilled completely between 195° and 208° and contained a considerable amount of acetophenone (b. p. 201°; lit., 202°; m. p. of 2 : 4-dinitrophenylhydrazone 249°; lit., 249°). No alcohols could be detected.

On evaporation of the ether from the acid extract, a residue of benzoic acid was obtained. Tests for ketonic acids and phenols were negative.

As with *n*-propylbenzene, the initial point of attack appears to be the α-carbon atom (cf. Stephens, *J. Amer. Chem. Soc.*, 1926, **48**, 1824, 2920). Acetophenone is the first isolable product and this is slowly further oxidised to benzoic acid.

Results and Discussion

Evolution of Carbon Dioxide.—The results in Table 1 show that the amount of carbon dioxide evolved during the oxidation of *n*-propylbenzene corresponds to complete oxidation of only 5·4% of the combined carbon in this compound. Since almost quantitative yields of benzoic acid are obtained, the small amounts of carbon dioxide must be formed by

* Part III, *J.*, 1955, 2850.

processes which do not involve appreciable disruption of the aromatic ring. The two most likely overall reactions are :

$$Ph{\cdot}CH_2{\cdot}CH_2{\cdot}CH_3 + 5O \longrightarrow Ph{\cdot}CO_2H + CH_3{\cdot}CO_2H + H_2O \quad . \quad . \quad . \quad . \quad (1)$$

$$Ph{\cdot}CH_2{\cdot}CH_2{\cdot}CH_3 + 9O \longrightarrow Ph{\cdot}CO_2H + 2CO_2 + 3H_2O \quad . \quad . \quad . \quad . \quad . \quad (2)$$

According to (2) the percentage of combined carbon completely oxidised is 22·2%. It is evident therefore that (1) is the predominant reaction and that only 5·4/22·2 × 100%, *i.e.*, 24·3%, of the organic compound is oxidised *via* reaction (2).

With *iso*propylbenzene, the carbon dioxide evolved must come from the two β-carbon atoms. If the overall reaction is :

$$Ph{\cdot}CH(CH_3)_2 + 5O \longrightarrow Ph{\cdot}CO{\cdot}CH_3 + CO_2 + 2H_2O \quad . \quad . \quad . \quad . \quad . \quad (3)$$

the percentage of combined carbon completely oxidised is 11·1%.

TABLE 1.

Temp. : 50°. Solvent : 54·2% w/v aqueous acetic acid.

[Organic compound] = 0·0103M ; [$KMnO_4$] = 0·103M.

	Compound taken (g.)	Wt. (g.), corr. for oxidn. of solvent, of $BaCO_3$	Wt. (g.), corr. for oxidn. of solvent, of CO_2	Organic compound completely oxidised (%)
PhPr^n	0·1202	0·0956	0·0212	5·4
	0·1202	0·0960	0·0214	5·4
PhPr^i	0·1202	0·3221	0·0719	18·1
	0·1202	0·3264	0·0727	18·4

If, on the other hand, oxidation proceeds according to the equation :

$$Ph{\cdot}CH(CH_3)_2 + 9O \longrightarrow Ph{\cdot}CO_2H + 2CO_2 + 3H_2O \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

the corresponding value is 22·2%. The observed extent of carbon dioxide evolution (Table 1) lies between these two values, no doubt owing to the slow but appreciable further oxidation of acetophenone to benzoic acid. Measurements of the amounts of benzoic acid and carbon dioxide formed at various stages of reaction suggest that, with this compound too, little disruption of the aromatic ring occurs.

It is thus found in general that, as the size of the alkyl group is increased in the monoalkylbenzenes, the extent of ring rupture diminishes (cf. Parts I and III).

Stoicheiometry.—The amount of permanganate needed in practice to oxidise *n*-propylbenzene was found by allowing the organic compound to react with an excess of oxidising agent, until the residual oxidising power of the solution showed only a slight decrease with time characteristic of the rate of oxidation of benzoic acid and of the solvent. The results in Table 2 confirm the conclusion, reached from measurements of carbon dioxide evolution, that the predominant reaction is (1), involving conversion of *n*-propylbenzene into benzoic acid and acetic acid. If x is the percentage of reaction which proceeds via (2), it follows from the figures given in Table 2, that $[6{\cdot}0x + 3{\cdot}3(100 - x)]/100 = 4{\cdot}0$, whence $x = 26{\cdot}0\%$. This value of x is in good agreement with that (24·3%) obtained from measurements of carbon dioxide evolution.

The corresponding measurements of the stoicheiometry of the reaction cannot be made with *iso*propylbenzene, owing to the formation of a moderately stable intermediate compound, acetophenone, which is only slowly further oxidised to benzoic acid.

TABLE 2.

Temp. : 50°. Solvent : 54·2% w/v aqueous acetic acid.

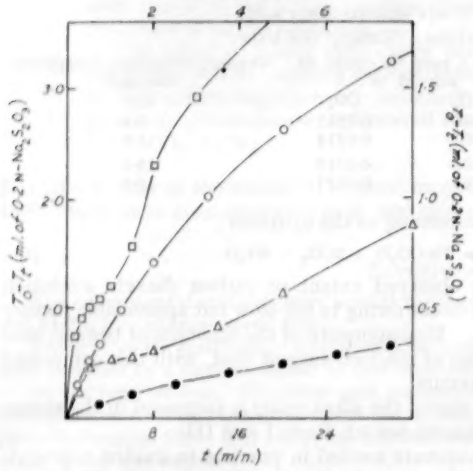
[Ph·Pr^n] = 0·00517M ; [$KMnO_4$] = 0·0413M.

	Found	Theor. [reaction (1)]	Theor. [reaction (2)]
Moles of $KMnO_4$ reqd. to oxidise 1 mole of PhPr^n	4·01, 4·05, 3·94 Average : 4·0	3·3	6·0

The Development of Reaction with Time.—The reaction–time curves for the oxidation of *n*-propylbenzene (Fig. 1) are of similar form to those obtained with toluene and ethylbenzene (Cullis and Ladbury, *J.*, 1955, 555, 2850). Those for *iso*propylbenzene, on the

other hand, exhibit a very high initial rate followed by a slower reaction which develops autocatalytically with time, particularly when the oxidising agent is in excess, as shown by the typical reaction–time curves in Fig. 1. The amount of permanganate which has been taken up when the initial fast reaction ceases does not correspond to the formation of any likely intermediate compound. The observed behaviour suggests that the *iso*propylbenzene may contain a small amount of an easily oxidisable impurity, such as α-methylstyrene, which rapidly consumes permanganate in the early stages of reaction. The *iso*propylbenzene used was carefully purified and its measured b. p. and refractive index agreed very well with recorded values. Nevertheless, several samples of the compound were subjected to different degrees of purification, and one sample was shaken twice with 60% w/v sulphuric acid to remove unsaturated compounds. No differences in reactivity

FIG. 1. *Reaction–time curves for the oxidation of* n- *and* iso-*propylbenzene.*

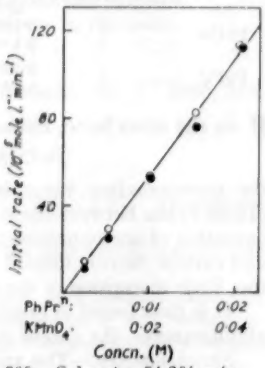


Temp.: 50°. Solvent: 54·2% w/v aqueous acetic acid.

○ $[PhPr^n] = 0{\cdot}02$M; $[KMnO_4] = 0{\cdot}02$M.
● $[PhPr^n] = 0{\cdot}01$M; $[KMnO_4] = 0{\cdot}005$M.
□ $[PhPr^i] = 0{\cdot}01$M; $[KMnO_4] = 0{\cdot}04$M.
△ $[PhPr^i] = 0{\cdot}005$M; $[KMnO_4] = 0{\cdot}02$M.

The left-hand ordinates and lower abscissæ refer to *n*-propylbenzene, and the right-hand ordinates and upper abscissæ to *iso*propylbenzene. The ordinate values may be converted into "moles of $KMnO_4$ per litre" by multiplication by the factor: $3{\cdot}442 \times 10^{-2}$.)

FIG. 2. *The dependence of initial oxidation rate on reactant concentration.*



Temp.: 50°. Solvent: 54·2% w/v aqueous acetic acid.

○ $[PhPr^n] = 0{\cdot}01$M; $[KMnO_4]$ varied.
● $[KMnO_4] = 0{\cdot}02$M; $[PhPr^n]$ varied.

were, however, detected for any of the samples investigated. It was therefore concluded that the characteristic shape of the reaction–time curves was an integral part of the behaviour of the pure compound.

The curves for *iso*propylbenzene are of the same form as, though more pronounced than, those for *o*-xylene and *o*-toluic acid (Cullis and Ladbury, *J.*, 1955, 1407). Similar behaviour is found in the oxidation of *p*-nitrophenol (Hinshelwood, *J.*, 1919, 1180).

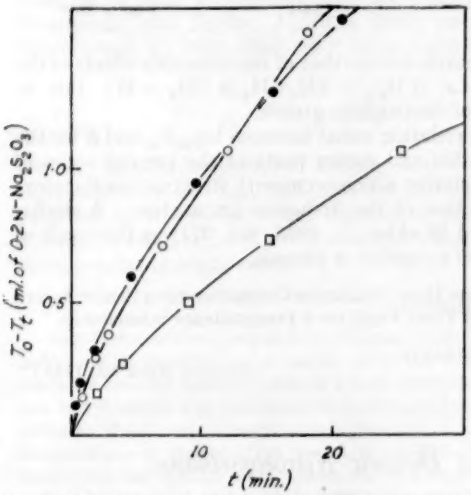
Influence of Reactant Concentrations.—As with the lower monoalkylbenzenes, the initial rate of oxidation of *n*-propylbenzene is of the first order with respect to both the organic compound and the oxidising agent (Fig. 2). The very rapid initial reaction of *iso*propylbenzene does not allow the rate to be determined accurately, and no reliable conclusions can be drawn as to the influence of reactant concentrations on the initial rate of oxidation of this compound.

Influence of Added Salts.—With *n*-propylbenzene, the effect of additions of manganous

and pyrophosphate ions follows closely that found with toluene (Cullis and Ladbury, *J.*, 1955, 555). Mn^{2+} ions cause the initial oxidation rate to increase (Fig. 3), owing to formation of reactive intermediate manganese ions; the subsequent reaction is retarded owing to reduction of MnO_4^- ions by Mn^{2+} ions to give manganese dioxide. Addition of sufficient pyrophosphate ions, which remove intermediate manganese ions, reduces the rate to a limiting value; in presence of 0·02M-$K_4P_2O_7$, the maximum depression is obtained, which amounts to about one-half of the original rate (Fig. 3).

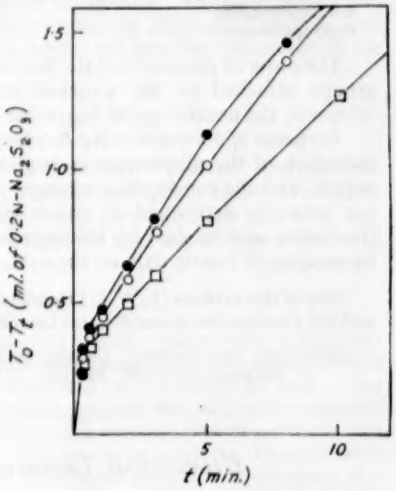
Manganous and pyrophosphate ions, on the other hand, do not appear to affect the initial high oxidation rate of *iso*propylbenzene (Fig. 4), though they alter the rate of the second stage of reaction. The results in Table 3 suggest that the importance of the rôle of intermediate manganese ions, as measured by the limiting reduction in rate on addition of

FIG. 3. *Reaction–time curves for the oxidation of* n-*propylbenzene in absence and in presence of added salts.*



Temp. 50°: Solvent: 54·2% w/v aqueous acetic acid.
[PhPr^n] = 0·01M; [$KMnO_4$] = 0·02M.
○ No added salt.
● [$MnSO_4$] = 0·005M.
□ [$K_4P_2O_7$] = 0·02M.

FIG. 4. *Reaction–time curves for the oxidation of* iso*propylbenzene in absence and in presence of added salts.*



Temp.: 50°. Solvent: 54·2% w/v aqueous acetic acid.
[PhPr^i] = 0·01M; [$KMnO_4$] = 0·02M.
○ No added salt.
● [$MnSO_4$] = 0·005M.
□ [$K_4P_2O_7$] = 0·02M.

excess of pyrophosphate ions, depends to a marked extent on the nature of the group in the α-position to the aromatic ring. The fact that pyrophosphate ions are without influence on the initial rate of oxidation of *iso*propylbenzene suggests that, in the early stages of reaction, the MnO_4^- ion is the sole active oxidising entity. The importance of intermediate manganese ions evidently decreases, and hence presumably the importance of MnO_4^- ions increases, according to whether the α-carbon atom is primary, secondary, or tertiary.

TABLE 3.

Temp.: 50°. Solvent: 54·2% w/v aqueous acetic acid.
[Organic compound] = 0·01M; [$KMnO_4$] = 0·02M; [$K_4P_2O_7$] = 0·02M.

Compound	PhMe	PhEt	PhPr^n	PhPr^i
$\frac{\text{Inhibited rate in presence of } K_4P_2O_7}{\text{Uninhibited rate}}$	0·30	0·62	0·56	1·00

Influence of Temperature.—The initial rates of reaction of permanganate with *n*- and *iso*-propylbenzene at 50° and the Arrhenius parameters for the oxidation of the former

compound (calculated from rate measurements in the temperature range, 40—60°) are shown in Table 4, together with the corresponding data for the lower monoalkylbenzenes. The values of A exhibit a similarity for *n*-propylbenzene and ethylbenzene but an appreciable difference for these two compounds as compared with toluene. This difference between the first and higher members of the homologous series is no doubt due to the change from a CH_3 to a CH_2 group in the α-position to the aromatic ring, which, it has already been seen, also affects the relative amounts of oxidation performed by the different oxidising species present (Table 3).

TABLE 4.

Solvent : 54·2% w/v aqueous acetic acid. [Organic compound] = 0·01M; $[KMnO_4]$ = 0·02M.

Compound	$10^5 \times$ Initial oxidation rate (at 50°) (mole $l.^{-1}$ $min.^{-1}$)	E (kcal. $mole^{-1}$)	A (l. $mole^{-1}$ $min.^{-1}$)
Toluene	16·6	13·2	$6{\cdot}45 \times 10^8$
Ethylbenzene	34·7	14·8	$1{\cdot}87 \times 10^{10}$
n-Propylbenzene	50·8	14·4	$1{\cdot}50 \times 10^{10}$
*iso*Propylbenzene	*ca.* 520	—	—

The order of reactivity of the four compounds follows that of the inductive effects of the groups attached to the α-carbon atom, *i.e.* $(CH_3)_2 > CH_3{\cdot}CH_2 > CH_3 > H$; this is, of course, the usual order of increasing ease of electrophilic attack.

Influence of Structure.—No functional correlation exists between $\log_{10} k_{50}$ and E for the oxidation of the alkylbenzenes studied in this and earlier parts of the present series of papers, and the considerable changes in reactivity which occur with structure are therefore not primarily dependent on either one or other of the Arrhenius parameters. A similar conclusion was reached by Hinshelwood and Winkler (*J.*, 1936, 368, 371) as the result of an analysis of kinetic data on the oxidation of a number of phenols.

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Geometrical Isomerism of Dimeric Nitrosomethane.

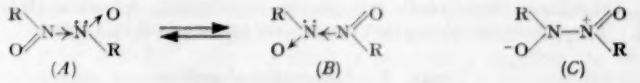
By B. G. GOWENLOCK and J. TROTMAN.

[Reprint Order No. 6511.]

Dimeric nitrosomethane is prepared by the photolysis of *tert.*-butyl nitrite vapour when nitrosomethane monomer dimerizes at an un-irradiated surface. A different dimer is prepared by dimerization at an irradiated surface or at low temperatures. The ultraviolet and infrared absorption spectra and other properties of the isomers are discussed, geometrical isomerism being invoked to explain them. The nitroso–hydroxyimino-system is briefly discussed. It is concluded that in the pyrolytic production of nitrosomethane from *tert.*-butyl nitrite some molecular elimination of nitrosomethane occurs.

BAMBERGER AND SELIGMAN (*Ber.*, 1903, **36**, 685) considered that it would be difficult to isolate nitrosomethane after oxidation of methylamine owing to its speedy isomerization to formaldoxime. Similarly, in the inhibition of free-radical chain reactions by nitric oxide, the reaction sequence $CH_3{\cdot} + NO \longrightarrow CH_3{\cdot}NO \longrightarrow H_2C{:}N{\cdot}OH$ has been assumed to be rapid. Although nitrosomethane has not been isolated on reaction of methyl radicals with nitric oxide, formaldoxime was isolated on decomposition of di-*tert.*-butyl peroxide in the presence of nitric oxide (Raley, Rust, and Vaughan, *J. Amer. Chem. Soc.*, 1948, **70**, 88) and on pyrolysis of *tert.*-butyl nitrite (Yoffe, *Research*, 1954, **7**, S 44). Nitrosoalkanes, together with the isomeric oximes, have been obtained by Chilton and Gowenlock (*J.*, 1953,

3232; 1954, 3174) on reaction of *iso*propyl and ethyl radicals with nitric oxide. This method utilizes mercury dialkyls as the source of the free radicals and weight yields are small owing to the small weight proportion of the alkyl groups in mercury alkyls. Nitrosomethane has been isolated as the dimer on photolysis of *tert.*-butyl nitrite (Coe and Doumani, *J. Amer. Chem. Soc.*, **1948**, **70**, 1516; Tarte, *Bull. Soc. roy. Liége*, **1953**, **22**, 26) and some of its simple properties have been briefly discussed.



(*A*) (*B*) (*C*)

Dimeric nitroso-compounds have been formulated as resonance hybrids (*A*) ⇌ (*B*) (Hammick, New, and Williams, *J.*, 1934, 29) or resonance forms of the type (*C*) (Fenimore, *J. Amer. Chem. Soc.*, 1950, **72**, 3226; Darwin and Hodgkin, *Nature*, 1950, **166**, 827). However, it is well established that *cis–trans*-isomerism is possible for azo- (Campbell, Henderson, and Taylor, *J.*, 1953, 1281) and azoxy-compounds (Brough, Lythgoe, and Waterhouse, *J.*, 1954, 4096), so it seems reasonable to invoke *cis–trans*-isomerism (*D*, *E*) for

(*D*) (*E*)

dimeric nitroso-compounds. Chilton and Gowenlock (*loc. cit.*) reported that dimeric nitrosomethane had $\lambda_{max.}$ 266—267 mμ (in H_2O) and 287 mμ (in Et_2O). Later, a specimen prepared by irradiation under different conditions (Coe and Doumani, *loc. cit.*) had $\lambda_{max.}$ 276 mμ (in H_2O) and 287 mμ (in Et_2O), indicating a possibility that two different dimers of nitrosomethane might exist.

Experimental

tert.-Butyl nitrite, prepared by Coe and Doumani's method (*loc. cit.*), was purified by repeated bulb-to-bulb distillation *in vacuo*, only the middle fractions being retained. Nitrogen was made by heating sodium azide in a high vacuum, being released into an evacuated bulb. The *tert.*-butyl nitrite was pyrolyzed in Chilton and Gowenlock's apparatus (*loc. cit.*), with a nitrogen pressure of ~4 mm., a butyl nitrite pressure of ~0·1 mm., and a reaction time of ~0·5 sec., the temperature of the reaction vessel being 330—390°. The pyrolysis products, together with undecomposed nitrite, were condensed in a trap cooled with liquid oxygen, and consisted of a yellow-brown solid and a white solid. On warming, the latter soon melted to a faintly yellow liquid, and the yellow-brown solid gave a yellow-brown liquid which rapidly changed to a white solid (X), the melting and resolidifying taking place between −45° and −40° (measured as by Chilton and Gowenlock, *loc. cit.*). The faintly yellow liquid was distilled off *in vacuo*. It boiled at 60—61°/760 mm., contained small amounts of *tert.*-butyl nitrite, and gave acetone semicarbazone, m. p. and mixed m. p. 187°. During the pyrolysis an increase in pressure was regularly observed; admission of air to the apparatus gave brown vapours, indicating that this increase was due, in part or in whole, to nitric oxide which is not completely condensed in liquid oxygen. The white solid (X) had the composition C, 26·9; H, 6·8; N, 30·2% (Calc. for CH_3ON: C, 26·7; H, 6·7; N, 31·1%), and was dissolved in aqueous ethanol at about 30° and then cooled in solid carbon dioxide–acetone; colourless crystals of *dimeric nitrosomethane*, m. p. 97·5°, were deposited [Found: C, 27·0; H, 6·5; N, 29·4%; *M* (cryoscopic in benzophenone), 92·0. CH_3ON requires C, 26·7; H, 6·7; N, 31·1%; *M*, 90].

Photolysis was effected in a 250-ml. transparent silica bulb or in a transparent silica trap of length 14 cm. and diameter 3 cm. In both cases about 1 ml. of *tert.*-butyl nitrite was in the vessel and was shielded from ultraviolet light; its pressure was about 110 mm. When the bulb was used, the vapour was irradiated for *ca.* 150 mm. by a Hanovia S500 lamp focused by means of a silica bulb containing water, or by a Thermal Syndicate Mercury Vapour Discharge lamp T/M5/369 placed within 2 cm. of the bulb: the former led to long needles of dimeric nitrosomethane, m. p. 122°, obviously identical with Coe and Doumani's and Tarte's specimens (*locc. cit.*); the latter led to small crystals with ultraviolet absorption maxima identical with those of the white solid (X). When the trap was used, irradiation was performed (*a*) with the Hanovia lamp placed 2 cm. from the trap, for 90 min., (*b*) with the Thermal Syndicate lamp

placed 2 cm. from the trap, for 90 min., or (*c*) with the Hanovia lamp placed 12 cm. from the trap, for *ca.* 300 min., most of the trap being shielded by a Pyrex beaker. Under conditions (*a*) and (*b*) the above-mentioned small crystals were obtained, and under conditions (*c*) the long needles, m. p. 122°.

Ultraviolet Absorption Spectra.—All measurements were made with a Unicam SP 500 photoelectric quartz spectrophotometer with corrected scale and 1-cm. or 0·5-cm. quartz cells. Solvents were water, ethanol (Bladon, Henbest, and Wood, *J.*, 1952, 2738), carbon tetrachloride (Spectrosol), chloroform (Spectrosol), *cyclo*hexane (Spectrosol), *n*-hexane (B.D.H.), or ether (McFarlane). The ultraviolet absorption spectra are summarised in Table 1.

TABLE 1. *Ultraviolet absorption.*

	Dimer A (m. p. 122°)		Dimer B (m. p. 97·5°)	
Solvent	$\lambda_{max.}$ (mμ)	log ε	$\lambda_{max.}$ (mμ)	log ε
H_2O	276	4·03	265	4·00
EtOH	282·5	4·01	269 *	4·00
$CHCl_3$	286	4·05	275 †	4·00
Et_2O	286	4·01	286 ‡	—
	213	3·48	213 ‡	—
*cyclo*Hexane	288	3·99	288 ‡	—
	218	3·14	218 ‡	—
n-C_6H_{14}	288	3·97	288 ‡	—
	218	3·12	218 ‡	—
CCl_4	291	4·06	291 ‡	—

* Increases slowly with time (282·5 mμ after 36 hr.). † Increases with time (286 mμ after 20 hr.). Warming to 60° for 30 sec. gives $\lambda_{max.}$ 286 mμ. Product after storage and crystallisation has m. p. 122°, $\lambda_{max.}$ 276 mμ (in H_2O). ‡ Dimer B was only slightly soluble (log ε not determined). Solvent was removed under reduced pressure and water added, or the product was directly extracted with water; $\lambda_{max.}$ was 276 mμ in H_2O. These figures indicate conversion of dimer B into dimer A in these solvents.

The effect of heat on both solids was investigated, a Kofler block being used. Dimer A melted at 122° to a colourless liquid giving a momentary blue-green colour at about 125°. Dimer B melted at 97·5° to a colourless liquid giving a pale-green colour between 108° and 135°. Each solid was then heated rapidly to the m. p., and cooled, and dissolved in water and the ultraviolet absorptions were determined: both products had $\lambda_{max.}$ 276 mμ and increased absorption at 210 mμ, presumably owing to formation of formaldoxime ($\lambda_{max.}$ <210 mμ).

The effect of heat on solutions of the two solids, investigated by means of the ultraviolet absorptions, is shown in Table 2, increased absorption at 210 mμ in H_2O or EtOH being considered as evidence for oxime formation.

TABLE 2. *Products formed by heating of solutions.*

Solvent	Dimer A	Dimer B
H_2O	Oxime	Oxime + A ($\lambda_{max.}$ 276 mμ)
EtOH	Oxime	Oxime + A ($\lambda_{max.}$ 282·5 mμ)
Et_2O	Oxime ($\lambda_{max.}$ 207 mμ)	—

The effect of ultraviolet irradiation (Hanovia lamp) is summarised in Table 3.

TABLE 3. *Products of ultraviolet irradiation of solutions.*

Solvent	Dimer A	Dimer B
H_2O	Oxime + B ($\lambda_{max.}$ 265 mμ)	Oxime
EtOH	Oxime + B ($\lambda_{max.}$ 269 mμ)	Oxime

Dimer A, which was more volatile than dimer B, was pyrolyzed at 350° under flow conditions similar to those used for *tert.*-butyl nitrite. A blue solid, condensed by liquid oxygen, gave a white solid on warming. The latter in aqueous solution had $\lambda_{max.}$ 265 mμ and gave only slight increase in intensity of absorption at 210 mμ compared with a pure specimen of B, indicating only slight formation of formaldoxime.

Solubilities.—Both dimers were easily soluble in water. In other solvents, dimer B was less soluble than dimer A (see Table 1 for evidence of interconversion). In general, it appeared that solubility decreased with decreasing dielectric constant of the solvent, dimer B being almost insoluble in solvents of low dielectric constant and converted into A on dissolution. Neither

form gave a blue colour on dissolution or gentle warming. In boiling chloroform, ethanol, and methanol dimer B gave blue colours and both dimers gave blue colours in boiling toluene or 1- or 2-nitropropane.

Spot Tests.—Both dimers gave the diphenylamine–concentrated sulphuric acid test (Coe and Doumani, *loc. cit.*); they did not give the Liebermann nitroso-test (Feigl, "Spot Tests," Elsevier, Amsterdam, 1939, p. 267), yellow-green colours in sulphuric acid and yellow-brown colours in sodium hydroxide solution being produced.

Effect of Solvents on Monomeric Nitrosomethane.—Monomeric nitrosomethane (produced pyrolytically) with nitrogen as carrier gas and other pyrolysis products was passed over solvents maintained at +5° or at −78°. Also the effect of condensing together the monomer and solvent at liquid-oxygen temperature was investigated. Solvents investigated at −78° gave blue-green colours; no colour was observed at +5°; at −183° the usual yellow-brown solid was formed. In each case, after warming to room temperature, the solvent was pumped off and the

TABLE 4. *Effect of solvent on* $CH_3 \cdot NO$.

Solvent	+5°	−78°	−183°
H_2O	No dimer, oxime formed	—	No dimer, oxime formed
MeOH	—	Dimer B	Dimer B
EtOH	No dimer, oxime formed	—	Dimer B
CCl_4	Trace of dimer B, oxime formed	—	CCl_4-insol., dimer B CCl_4-sol., $\lambda_{max.}$ 271 mμ (?A + B)
Et_2O	—	Dimer B	Dimer B

ultraviolet absorption of the residue in water was determined. With carbon tetrachloride at −183°, the product dissolved only partly on warming to room temperature; separation into two portions was thus achieved and the absorption of each in water was determined; insoluble material was always white. Table 4 summarizes the results, strong absorption below 220 mμ (in H_2O) with a peak below 200 mμ again being taken as evidence for oxime formation. Except where specified, "$\lambda_{max.}$ 265 mμ" indicates formation of dimer B, and "$\lambda_{max.}$ 276 mμ" indicates formation of dimer A.

Infrared Absorption Spectra [carried out by M. ST. C. FLETT].—The following infrared absorption bands (cm.$^{-1}$) were measured on a Grubb-Parson S4 double beam spectrophotometer (w = weak, m = medium intensity, s = strong, vs = very strong):

Trimeric formaldoxime (2 mg. in 0·350 g. of KBr): 3448 s, 3279 s, 2942 m, 2415 w, 2364 w, 2083 w, 1631 m, 1464 m, 1385 vs, 1198 w, 1147 m, 1124 m, 1036 m, 958 m, 842 s.

Dimer A (2 mg. in 0·170 g. of KBr): 3049 s, 1543 w, 1427 m, 1397 s, 1282 vs, 1130 vs, 936 vs, 824 w, 766 w.

Dimer A (2·5% in $CHCl_3$; 0·1-mm. cell): 3004 m, 1520 w, 1477 w, 1422 m, 1395 m, 1294 vs, 1208 vs, 1144 m, 1131 s, 1044 w, 934 s, 877 w, 848 w.

Dimer B (2 mg. in 0·170 g. of KBr): 3049 s, 2967 s, 1667 m, 1471 s, 1399 vs, 1342 vs, 1103 m, 1058 m, 1022 vs, 875 w, 740 s.

Dimer B (2·5% in $CHCl_3$; 0·1-mm. cell): 3003 m, 1513, w, 1481 w, 1405 m, 1341 w, 1297 s, 1231 m, 1143 w, 1132 w, 1042 w, 1025 w, 933 w, 875 w, 847 w.

DISCUSSION

It is shown that dimeric nitrosomethane exists in two interconvertible forms which, by analogy with azo- and azoxy-compounds, are probably *cis–trans*-isomers. It was suggested in a preliminary communication (Chilton, Gowenlock, and Trotman, *Chem. and Ind.*, 1955, 538) that dimer A is probably the *trans*- and dimer B the *cis*-isomer; the evidence for this may be summarized as follows. Dimer A can be obtained from dimer B by heat, the reverse change being effected by irradiation with ultraviolet light. It is well-known that maleic and fumaric acid and azo- and azoxy-compounds behave similarly. In addition it is known that some aromatic nitroso-dimers are *trans*-forms (Fenimore, *loc. cit.*; Darwin and Hodgkin, *loc. cit.*), as are the thermally stable azo-compounds. On molecular models it is impossible to form the *cis*-dimer of 2-methyl-2-nitrosopropane owing to the shape of the *tert.*-butyl groups. Similar considerations apply for other *tert.*-alkyl groups and for chlorinated *tert.*-alkyl groups. Tarte (*Bull. Soc. chim. belges*, 1954, **63**, 525) has determined the N–O frequency in the following solid dimeric nitroso-compounds: nitrosomethane 1294, 2-methyl-2-nitrosopropane 1268, 1-chloro-2-methyl-2-nitrosopropane 1236 cm.$^{-1}$.

These values may be compared with our values for dimer A (1282 cm.$^{-1}$). Dimer B shows no absorption maxima in this region, the N=O frequency being tentatively identified with the 1399 cm.$^{-1}$ absorption which is the strongest band in the spectrum. Comparison with the N–O frequency data for dimeric nitroso*cyclo*hexane (1198 cm.$^{-1}$), dimeric 4-nitrosoheptane (1183 cm.$^{-1}$), and dimeric α-nitrosotoluene (1166 cm.$^{-1}$) (Müller and Metzger, *Chem. Ber.*, 1955, **88**, 165) substantiates this argument, it being assumed that the N=O frequency decreases in dimers of type A with increasing size of the hydrocarbon group.

An approximate determination of the dipole moment of dimer A in benzene by Dr. J. W. Smith indicates that the dipole moment is less than 0·7 D and possibly zero. Owing to the rapid isomerization of dimer B into dimer A in solvents of low dielectric constant suitable for dipole-moment determination, it is impossible to measure the dipole moment of dimer B. On the basis of this evidence, we therefore assign the configurations *trans* and *cis* to dimers A and B respectively. It may be noted that Hammick, New, and Williams (*loc. cit.*) obtained a value of 0·99 ± 0·10 D for the dipole moment of dimeric 2 : 5-dimethyl-2-nitrosohexane which on steric grounds can only be the *trans*-isomer. This value is too high, as atom polarization has been neglected in calculating the dipole moment, and it is possible that the error limit suggested is too small in view of the assumptions made in calculating μ.

The *cis*-dimer appears to be the more stable at low temperatures, for in every experiment in absence of water the condensed monomeric nitrosomethane gave the *cis*-dimer on warming. Chilton and Gowenlock (*loc. cit.*) in their study of the reaction products of *iso*propyl and ethyl radicals with nitric oxide obtained $\lambda_{max.}$ values of 266—227 mμ (in H_2O) and 289—291 mμ (in Et_2O) which suggest that *cis*-dimers were obtained in these cases. The observation that such solids produced blue colours in solvents of low dielectric constant, this colour then fading, suggests a dissociation into the monomer and subsequent formation of the *trans*-dimer.

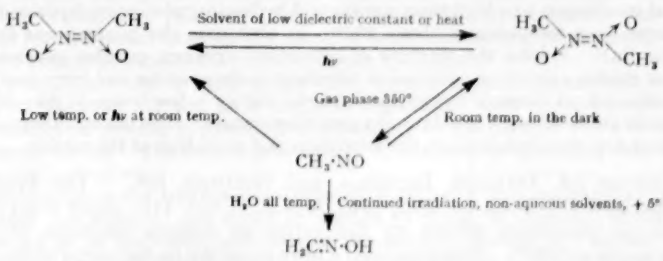
The early measurements by Baly and Desch (*J.*, 1908, **93**, 1747) of the absorption spectra of 2-methyl-2-nitrosopropane in ether, $\lambda_{max.}$ 300 (ε 100) and 655 mμ (ε 20), have been quoted as standard in Braude's review (*Ann. Reports*, 1945, **42**, 105), together with the incorrect name nitrosobutane. Jander and Haszeldine's more recent measurements (*J.*, 1954, 912) ($\lambda_{max.}$ 296 and 675 mμ) give no values for the extinction coefficients. The extinction coefficient datum for the lower-wavelength maximum is probably in error owing to dissociation into the monomer in ether, whereas the intensity of absorption associated with monomeric nitroso-compounds is of the right order, *i.e.*, ε 15—30 (Hammick *et al.*, *J.*, 1935, 1679; 1937, 489). Both *cis*- and *trans*-dimers show high intensity (ε ~ 10,000) in the ultraviolet spectrum and Müller and Metzger (*loc. cit.*) give ε values in the region 6800—12,200 for the dimeric nitroso-compounds which they have recently prepared. Thus, in relation to the intensity of absorption, dimeric nitroso-compounds show a much greater resemblance to azoxy-compounds (Langley, Lythgoe, and Rayner, *J.*, 1952, 4191), nitramines, and nitrosamines (Haszeldine and Jander, *J.*, 1954, 691) than to monomeric nitroso-compounds and nitroalkanes (Kortüm, *Z. phys. Chem.*, 1939, **43**, *B*, 271; *Z. Elektrochem.*, 1941, **47**, 55). The effect of solvent on the ultraviolet absorption is similar to that for other polar non-conjugated chromophoric groups, $\lambda_{max.}$ being displaced to lower wavelengths with increasing dielectric constant of the solvent [cf. acetone (Gillam and Stern, "Electronic Absorption Spectroscopy," Arnold, 1954, p. 264), the *R*-band of mesityl oxide (*op. cit.*, p. 265) and the long-wavelength band of ethyl diazoacetate (*op. cit.*, p. 57)]. There has been little, if any, consideration of this effect from a theoretical angle; it can be shown that a plot of $\lambda_{max.}$ against either log ε or $(\varepsilon - 1)/(2\varepsilon + 1)$ (where ε is the dielectric constant of the solvent) gives a smooth curve. The significance of such an empirical relation is unknown. The lower values for $\lambda_{max.}$ in ether (213 mμ), or *cyclo*hexane and *n*-hexane (218 mμ), are not due to oxime formation, formaldoxime giving peaks at 207 mμ in these solvents, but presumably are due to the dimeric nitroso-group's exhibiting a second characteristic peak. It is to be noted that both the aqueous and the ethanolic solution exhibit increasing absorption below 210 mμ, possibly owing to a maximum below 200 mμ.

In addition to dimerization, monomeric nitrosomethane can undergo isomerization to formaldoxime, and the mechanism of this nitroso–hydroxyimino-reaction is unknown. The facts that little formaldoxime is obtained in the pyrolysis of *tert.*-butyl nitrite or from

trans-dimeric nitrosomethane, and that in the direct reaction of gaseous alkyl radicals with nitric oxide (Chilton and Gowenlock, *loc. cit.*) little isomerization occurs, suggest an activation energy in the range 30—40 kcal./mole for the homogeneous gas-phase isomerization. Our results show that in water the reaction $CH_3{\cdot}NO \longrightarrow H_2C{:}N{\cdot}OH$ is much faster than the dimerization. In non-aqueous solvents at −78° this isomerization is slow relatively to dimerization, whereas at room temperature the reverse holds good. If the rate of dimerization is assumed to be independent of the solvent, an ionic or a polar mechanism is probable for the isomerization. Alternatively if the rate of isomerization is independent of the solvent, then decrease in the dielectric constant of the solvent increases the rate of dimerization. An unambiguous answer cannot be given on the evidence available. The rapidity of the isomerization in water at room temperature affords a convincing explanation of the failure to isolate nitrosoalkanes containing α-hydrogen by controlled oxidation of the corresponding amine. Bamberger and Seligman's method (*loc. cit.*) for the oxidation, $Bu^t{\cdot}NH_2 \longrightarrow Bu^t{\cdot}NO$, was applied to *iso*propylamine under similar conditions. No blue colour was observed in the ether layer, and ultraviolet spectrophotometry indicated at most minute quantities of dimeric nitroso-compound in relation to oxime formation. The isolation of α-nitrosotoluene on oxidation of *N*-benzylhydroxylamine (Behrend and Konig, *Annalen*, 1891, **263**, 212) is probably associated with the greater stability of the CH_2 group in benzyl compounds. Our evidence suggests that other preparative methods for nitrosoalkanes containing α-hydrogen might succeed in non-aqueous solvents where the tendency for the isomerization to the oxime could be suppressed by use of low temperatures. Alternatively, controlled oxidation of azo- and azoxy-alkanes should avoid the possibility of this speedy isomerization.

The conversion of the *cis*- into the *trans*-dimer in solvents of low dielectric constant may be ascribed to the increased energy of repulsion between the adjacent semi-polar N→O groups in such media. This would suffice to overcome the energy barrier for conversion into the *trans*-dimer in which the repulsion would be considerably reduced.

The reactions of nitrosomethane are summarised in the diagram.



It remains to discuss the mechanism given by Yoffe (*loc. cit.*) for the decomposition of *tert*-butyl nitrite; he proposed

$$(CH_3)_3C{\cdot}O{\cdot}NO \longrightarrow (CH_3)_3C{\cdot}O{\cdot} + NO \quad (1)$$

$$(CH_3)_3C{\cdot}O{\cdot} \longrightarrow (CH_3)_2CO + CH_3{\cdot} \quad (2)$$

$$CH_3{\cdot} + NO \longrightarrow CH_3{\cdot}NO \longrightarrow (H_2C{:}N{\cdot}OH)_2 \quad (3)$$

$$2CH_3{\cdot} \longrightarrow C_2H_6 \quad (4)$$

$$CH_3{\cdot} + (CH_3)_2CO \longrightarrow CH_4 + {\cdot}CH_2{\cdot}CO{\cdot}CH_3 \quad (5)$$

$$CH_3{\cdot} + {\cdot}CH_2{\cdot}CO{\cdot}CH_3 \longrightarrow \tfrac{1}{2}C_2H_5{\cdot}CO{\cdot}CH_3 \quad (6)$$

Our main products—nitrosomethane, acetone, and nitric oxide—could arise by this mechanism. [Reaction (3) implies formaldoxime dimer—this should be the trimer.] However, Yoffe's products do not account for his mechanism, the carbon balance being incorrect. Also, under these conditions, the concentrations of methyl radicals and nitric oxide being approximately equal, the relative yields of ethane and nitrosomethane should be proportional to the relative collision efficiencies of reaction 4 and 3 (Durham and Steacie,

J. Chem. Phys., 1952, **20**, 582), *i.e.*, ~100 : 1. Yoffe's results however give a ratio of 0·05 : 1. It is therefore necessary to suggest that the predominating reaction is the molecular decomposition :

$$(CH_3)_3C{\cdot}O{\cdot}NO \longrightarrow (CH_3)_2CO + CH_3{\cdot}NO$$

Support for such a mechanism is given by the predominance of the *trans*-rotational isomer of *tert.*-butyl nitrite (Tarte, *ibid.*, 1952, **20**, 1570) and would thus afford a molecular decomposition mechanism for both photolysis and pyrolysis of *tert.*-butyl nitrite. Production of nitric oxide in the pyrolytic decomposition is due to Yoffe's reaction (1). Pyrolysis of the *trans*-dimer under similar conditions to those used for *tert.*-butyl nitrite yields the *cis*-dimer *via* monomeric nitrosomethane. This suggests that the reaction $CH_3{\cdot}NO \longrightarrow CH_3{\cdot} + NO$ could participate to a very small extent at most.

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The Preparation and Properties of Some Plutonium Compounds. Part II. Plutonium Nitride.*

By F. BROWN, HEATHER M. OCKENDEN, and G. A. WELCH.

[Reprint Order No. 6520.]

Plutonium nitride has been prepared by two methods: by heating the metal in nitrogen to a high temperature and by heating plutonium hydride in nitrogen to a temperature above 230°. In each case the product was the same, PuN. Unlike the mixture of refractory uranium nitrides obtained under similar conditions, plutonium nitride is quite reactive and very easily decomposed. Complete hydrolysis occurred within a few hours at 80—90° in moist air or within a few days at room temperature. The use of a thermobalance has provided data on the formation and oxidation of the nitride.

IN 1944, Westrum (cf. Abraham, Davidson, and Westrum, jun., "The Transuranium Elements," McGraw-Hill Book Co. Inc., 1949, N.N.E.S., Vol. 14B, paper 6.60) attempted a preparation of plutonium nitride by the action of gaseous ammonia at 250 mm. on plutonium metal at 1000°. This produced a brown coating on the metal which according to Zachariasen's *X*-ray diffraction analysis (*op. cit.*, paper 20.2; Report A.N.L. 4552, Dec. 8th, 1950, p. 15) consisted of 40% of PuO_2, 35% of PuN, and 25% of unidentified matter. Abraham (*op. cit.*) then heated plutonium trichloride in gaseous ammonia at 900° and obtained a mixture of PuO_2 50%, PuN 35%, and PuOCl 15%. Finally, Westrum (*op. cit.*) overcame the difficulty of oxide formation by heating plutonium hydride in gaseous ammonia at 650°/250 mm., obtaining a product which was identified by Zachariasen as a single phase, PuN. It was brown with a face-centred cubic sodium chloride structure. No other information on the chemistry of plutonium nitride has been found in the literature or in available classified reports.

We proposed first to study the plutonium–nitrogen system briefly and then to obtain a pure sample of nitride, probably by some other means, for the examination of its properties.

A thermobalance built for use with radioactive materials proved very useful in this work. It was found that plutonium metal reacted with nitrogen to a slight extent at temperatures above about 250°, but that the reaction was only a surface one and even prolonged heating of milligram amounts at 800—1000° did not cause complete conversion into nitride.

* Part I, *J.*, 1955, 3932.

In associated work (*J.*, 1955, 3932) we had found that plutonium metal reacted rapidly with hydrogen at 200°. This finely divided hydride proved to be a much more convenient starting point; at 230° it reacted with nitrogen, forming a practically pure nitride.

The pure nitride was black but became light brown after a few days owing to hydrolysis. (Westrum *et al.* reported a brown nitride prepared from plutonium hydride and ammonia.) It was dense and hard, like the metal, and brittle. It was attacked by mineral acids, both dissolution and oxidation to an insoluble hydrated oxide occurring; the nitrogen was converted quantitatively into ammonium salts. The most notable property was its ease of hydrolysis by heat and moist air. In contrast, uranium under the same conditions of preparation forms a mixture of U_2N_3 and UN_2 which is extremely stable and resistant to hydrolysis (Katz and Rabinowitch, "Chemistry of Uranium," McGraw-Hill Book Co. Inc., 1949, N.N.E.S., Vol. V; Rundle, Baenziger, Newton, Deane, Butler, Johns, Tucker, and Figard, Report A.E.C.D. 2247). The nitride UN, which is obtained only by heating the other nitrides to 1300°, is similarly resistant to attack.

X-Ray diffraction photographs of PuN showed a face-centred cubic system, isomorphous with PuO and identical with that reported by Zachariasen. A faint line due to PuO_2 was detected and was probably due to slight decomposition whilst the nitride was subjected to *X*-rays for several hours. The formula PuN was confirmed by (*a*) the weight of nitrogen absorbed by plutonium hydride, and (*b*) the increase in weight on oxidation of plutonium nitride and ignition of the product to plutonium dioxide.

Experimental

Apparatus.—The apparatus for heating plutonium metal in either hydrogen or nitrogen was very similar to the system described in the related paper reporting the preparation of plutonium hydride (Part I, *loc. cit.*). Inside the glove-box and immediately before the reaction tube was another, smaller tube, also surrounded by a furnace and containing uranium nitride at 600°, for purifying the nitrogen (Newton, U.S.P. 2,487,360/1945). The uranium nitride was made *in situ* by passing nitrogen through the tube packed with cleaned uranium turnings and asbestos wool heated to 800° (Newton and Johnson, U.S.P. 2,544,277/1945). Hydrogen was allowed to by-pass the uranium furnace before entering the reaction tube. As before, precautions were taken to keep an inert atmosphere inside the box when using hydrogen.

The thermobalance was a silica spring type, similar to that constructed at Harwell by Dawson (*J.*, 1954, 558). It was built partly in a glove-box with an inlet tube at the top for applying vacuum or passing in gases. The sensitivity of the balance was 0·909 mm./mg. for any load up to 50 mg. The overall precision (3 × standard deviation) of the weighings was ±0·15 mm. *i.e.*, ±0·17 mg.

Nitrogen for use in the balance was obtained as follows: The gas from a "White Spot" grade cylinder was analysed and found to contain 60 p.p.m. of oxygen. It was purified by adding 120 p.p.m. of hydrogen, and passing the mixture through a "Deoxo" gas purifier (Baker Platinum Ltd.) and then through a sulphuric acid bubbler to remove the water produced. The hydrogen was added by passing the nitrogen through the cathode compartment of a small glass electrolytic cell which was generating hydrogen at a known rate, proportional to the current. The flow rate of the nitrogen (400 ml./min.) was measured with a rotameter, and the current was adjusted accordingly to 6·3 ma, sufficient to generate 120 p.p.m. of hydrogen in the nitrogen. The purified nitrogen was passed into the evacuated balance until atmospheric pressure was reached. To ensure complete freedom from oxygen, the filling process was always repeated twice.

Method of Preparation.—(a) *From plutonium metal.* As in the preparation of plutonium hydride, the surface condition of the metal appeared to affect its rate of reaction considerably. All the following work was carried out with fresh samples of plutonium.

The first experiments were designed to find whether plutonium would react with nitrogen. A 20—50-mg. piece was weighed in a silica boat and placed in the combustion tube in a rapid stream of purified nitrogen. When all the air was displaced, the furnace was moved over the sample to heat it to a measured temperature for a fixed length of time. The sample was then allowed to cool in nitrogen before being removed to measure any increase in weight.

From Table 1, showing the results for ten samples of metal, it may be seen that a reaction does occur but is quite slow and incomplete even at 1000°. For 100% conversion into nitride

(PuN; cf. Zachariasen, *locc. cit.*), the increase in weight would be 5·86%. By using this figure and assuming that no other reaction took place, the percentage conversions into nitride were calculated from the increases in weight. Apart from a few inconsistencies due to varying relative surface areas and degree of tarnishing of the metal sample, it appeared that a

TABLE 1. *Summary of results obtained on heating plutonium metal in nitrogen in a combustion tube.*

Temp.	Time of heating (hr.)	Wt. of Pu sample (mg.)	Increase in wt. (mg.)	Calc. % of PuN	N, determined by analysis (mg.)
625°	16	35·0	0·06	3	0·07
800	4	21·7	0·05	2	—
800	16	32·4	0·24	12	—
900	5	11·8	0·29	42	0·23, 0·29
950	16	55·0	0·96	31	—
950	32	16·6	0·33	41	0·32
1000	0·5	25·7	0·16	11	—
1000	6	3·6	0·11	51	—
1000	12	50·7	0·64	22	—
1000	17	15·4	0·70	78	0·60, 0·61

temperature of more than 900° was required for the reaction to proceed to any extent, and even at 1000° the maximum conversion achieved was 78% in 17 hr. In several cases the result was checked by a nitrogen determination carried out by a Conway diffusion method described below. Good agreement was obtained between the nitrogen determined and the increase in weight.

The metal appeared to be altered very little by nitrogen, except for being more tarnished and more brittle than originally. *X*-Ray diffraction studies of the surface coating of nitride indicated a face-centred cubic system, the same as that found by Zachariasen and attributed to PuN.

One experiment was carried out to see whether sudden admission of nitrogen to plutonium, already heated to a high temperature, above its m. p., in an inert atmosphere, would cause disruption of the metallic structure and complete conversion into nitride. A 60-mg. sample of metal was heated in argon to 900°, then the argon was replaced by a rapid flow of nitrogen. After about 3 min., the sample was allowed to cool in nitrogen and removed for analysis. The metal was tarnished owing to a film of nitride (shown by *X*-ray diffraction). A nitrogen determination showed the plutonium nitride content to be only 0·8%. Therefore, even under these conditions the reaction is only at the surface.

To obtain more details about the extent of the reaction at various temperatures, plutonium metal was heated in nitrogen on a thermobalance. The increase in weight was measured at regular intervals while the temperature was raised by 30° during each 15 min. Several samples treated in this way gave very similar results: a slight increase in weight began as low as 200° but the reaction remained slow up to 900—1000° where it became more rapid. The increase in extension of the spiral (proportional to the increase in weight) was plotted against temperature, as shown in Fig. 1.

Sample A (Fig. 1) (58·12 mg. of plutonium) was heated to 970° during 4½ hr. and kept at 970° during a further 2 hr. At first there was a very small loss in weight, probably due to a trace of moisture. The overall increase in weight was 1·46 mg., the initial change being at about 200°. When the sample was dissolved in 2N-hydrochloric acid there was a small residue of oxide which was removed and dissolved in nitric acid containing fluoride. The plutonium content was determined radiometrically. The product was calculated to consist of PuO_2 0·8% (found radiometrically), PuN 43·6% (increase in weight corrected for PuO_2), and Pu metal 55·6% (by difference).

Sample B (49·43 mg. of plutonium) was heated more slowly to 550° during 6 hr., then cooled in nitrogen and dissolved in 4N-hydrochloric acid. The nitrogen was determined by the Conway diffusion method, and the remaining increase in weight was attributed to oxide formation. The obtained results were: PuO_2 3·7% (increase in weight corrected for PuN), PuN 4·7% (from nitrogen determination), and Pu metal 91·6% (by difference).

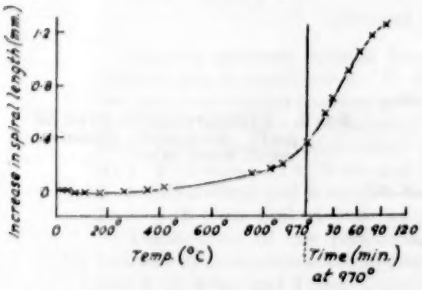
In each case a small amount of oxidation appears to have occurred, due to either moisture from the apparatus or a small leak of air during the 6—8 hours' heating.

Two other samples gave very similar results. It was therefore confirmed that the rate of reaction of plutonium metal with nitrogen is considerably increased above about 800° but is still relatively slow. Some reaction occurs at 300° or less, but is very slight in extent. Pure plutonium nitride, free from oxide and unchanged metal, was not obtained by this means.

(b) *Preparation from plutonium hydride.* The action of hydrogen on plutonium, leading to disintegration and formation of a hydride $PuH_{2\cdot7}$, was carried out as described earlier (Part I, *loc. cit.*). When the reaction was complete, the temperature was slowly raised to 800°; at the same time the flow of hydrogen was replaced by that of purified nitrogen. After about 2 hr. the sample was allowed to cool in nitrogen and was then removed for *X*-ray diffraction analysis. The pattern obtained was that of plutonium nitride, PuN, with a just discernible line due to plutonium dioxide. The oxide impurity could have been due to partial hydrolysis of the nitride whilst being subjected to *X*-rays, since plutonium nitride was subsequently found to be very unstable.

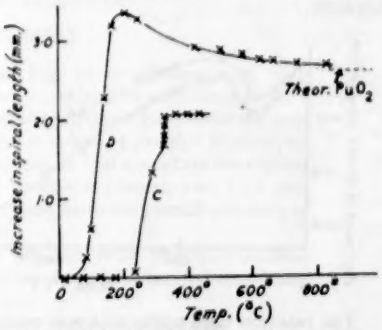
This appeared to be a quite simple and satisfactory method of preparation. To find the temperature at which plutonium hydride reacted with nitrogen, the reaction was carried out on the thermobalance. When heated to 230° during a period of 1½ hr. very little change took place. Then a sudden and rapid increase in weight was observed within 15 min., corresponding to a 63% conversion into plutonium nitride. The rate of heating was reduced and the reaction then became progressively slower, not reaching completion for another 2 hr. Further increase in temperature caused no increase in weight. Fig. 2 (curve *C*) shows the increase in spiral length (proportional to the increase in weight), plotted against temperature.

FIG. 1. *Thermogravimetric curves for plutonium metal heated in nitrogen.*



(The increase in spiral length corresponding to complete conversion into nitride would be 3·04 mm.)

FIG. 2. *Thermogravimetric curves.*



C, Plutonium hydride heated in nitrogen.
D, Plutonium nitride heated in air.

The extension due to Pu hydride = 45·68 mm. (50·27 mg.). The total increase in extension = 2·06 mm. The theoretical increase in extension for the reaction $PuH_{2\cdot7} \longrightarrow PuN$ = 2·13 mm. The experimental increase in weight was therefore 3·3% low but the difference represented a very small weight, 0·08 mg. (0·07 mm.), which was within the limits of precision of the balance. These results showed that plutonium hydride reacts with nitrogen at 240° to form the nitride PuN. This confirmed the formula calculated by Zachariasen from *X*-ray data (Zachariasen, *locc. cit.*). A second sample treated in the same way gave a very similar result.

Properties of Plutonium Nitride.—Like plutonium hydride, the nitride appeared very similar to the metal—black with sometimes a silvery lustre, hard, but brittle enough to be ground to a coarse powder. Whether prepared from the metal or the hydride, there was no apparent change in particle size, volume, or colour on formation.

Plutonium nitride is extremely unstable in air. When kept in a desiccator and removed periodically for weighing, it showed an increase in weight of 1·2% in 5 days. When exposed to moist air it increased its weight by 42% during the same time. The hydrolysis was accompanied by a considerable increase in volume and a change in colour from black to brown, then finally greenish yellow. *X*-Ray diffraction studies of the brown powder indicated a mixture of plutonium nitride and plutonium dioxide. The final product was plutonium dioxide.

The instability of plutonium nitride was very well illustrated by the results obtained on heating it in air on the thermobalance (Fig. 2, curve *D*). When heat was applied, a small but immediate increase in weight was observed. The temperature was raised at a rate of about 30° every 15 min., causing the increase in weight to become rapid at about 90°. The reaction was complete within another 45 min., the rate probably depending on the amount of moisture present

in the apparatus as well as on the temperature. The product was a partly hydrated oxide, which gradually lost moisture as the temperature was increased, forming the normal greenish-yellow plutonium dioxide. At 900°, the increase in weight was higher than that expected, by 5% (0·13 mm.), but the oxide was still losing moisture at an extremely slow rate. It appears therefore that plutonium nitride is very readily decomposed in moist air at quite a low temperature, the reaction being particularly fast at about 100°.

Fig. 3 shows the results obtained from two samples of nitride which had been stored in air in a stoppered tube for two weeks and had changed in appearance to a dark brown powder. Instead of the normal increase in weight, there was an initial decrease which, apart from a small increase at 90—100°, continued up to 400° where constant weight was attained. The graph clearly indicated a mixture of hydrated plutonium oxide and plutonium nitride, the hump at 90—100° being due to decomposition of the nitride. This was confirmed by *X*-ray diffraction data.

In cold water, plutonium nitride was slowly hydrolysed, but in hot water it expanded within a few seconds to a voluminous black mass and the water became alkaline to litmus.

Plutonium nitride, when freshly prepared, was dissolved by 3M-hydrochloric acid or -sulphuric acid in the cold, although a trace of residue was found presumably due to a competitive hydrolysis. The resulting solutions were blue, indicating the presence of tervalent plutonium. The sulphate solution became pink overnight owing to oxidation to more stable plutonium(IV) sulphate.

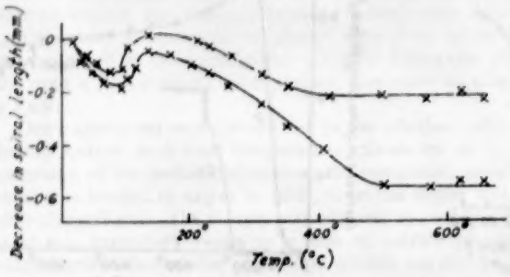


FIG. 3. *Thermogravimetric curves for partly decomposed plutonium nitride heated in air.*

The reaction with nitric acid was more complicated. The nitride was attacked slowly only on heating, part of it dissolving as nitrate and the remainder being converted into an insoluble, partly colloidal, black hydrated oxide. The relative amounts dissolved or oxidised depended on the concentration of the acid, the particle size of the nitride, the time of heating, and other factors. In one set of experiments, the percentages of nitride dissolved by nitric acid after 30 min. at 90—100° were: 8% in 3M-acid (0·24 mg. of Pu per ml.), 13% in 7·5M-acid (0·46 mg. of Pu per ml.), 35% in 15M-acid (1·11 mg. of Pu per ml.).

All the fresh samples of plutonium nitride gave good *X*-ray photographs corresponding to a face-centred cubic pattern of lattice parameter 4·905 ± 0·002 Å. This agreed well with Zachariasen's reported value of 4·906 Å. A faint pattern due to plutonium dioxide was just visible and was estimated to be due to about 1—2%. On storage, these samples gave progressively stronger oxide patterns and weaker nitride patterns.

Determination of Nitrogen in Plutonium Nitride.—The nitrogen figures quoted in Table 1, for partly nitrided plutonium metal, were found by a method we have used for determining microgram amounts of nitride nitrogen in plutonium metal. This is an adaptation of the Conway and Byrne diffusion method (*Biochem. J.*, 1933, **27**, 419) for determining ammonia and ammonium compounds. Our method consists in placing the sample dissolved in 3N-hydrochloric acid in a Conway diffusion cell (Conway, "Microdiffusion Analysis and Volumetric Error," Crosby-Lockwood, London, 1947) and liberating the nitrogen as ammonia; this diffuses into 0·1 ml. of 0·01N-sulphuric acid, and the excess of acid is then determined by a micro-titration with 0·01N-sodium hydroxide.

The level of nitrogen determined by this method was very low, of the order of 1—5 μg., and it was therefore necessary to take very small aliquot parts (with the consequent low precision) of the dissolved plutonium nitride. However, the results shown in Table 2 agreed within experimental limits with the apparent nitrogen content indicated by the increase in weight during preparation, thus confirming that the increases were due to nitrogen uptake. They also confirmed the conversion of the nitrogen into ammonium salts when the nitride was dissolved in dilute acid.

TABLE 2. *The determination of nitrogen (%) in plutonium nitride by a Conway diffusion method.*

Sample	Calc. from formula PuN	Found by increase in wt. when prepared	Found by Conway diffusion method
1	5·5	5·5	4·9, 4·8, 4·8
2	5·5	—	5·3, 5·2, 5·2, 5·2

The authors gratefully acknowledge the help given by J. B. Fardon and B. J. McDonald in performing the *X*-ray analyses. Thanks are offered to the Managing Director of this Group for permission to publish this paper.

U.K. ATOMIC ENERGY AUTHORITY (INDUSTRIAL GROUP),
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Wood Saponins. Part II. Further Studies on the Saponins from Morabukea* [Mora gonggrijpii (*Kleinh.*) *Sandwith*].

By R. H. FARMER and R. A. LAIDLAW.

[Reprint Order No. 6535.]

Saponin mixtures isolated from different logs of morabukea may vary considerably in constitution. In the present investigation a product of very low galactose content has been examined. Acid hydrolysis gave oleanolic acid (37%) and a mixture of D-glucose (9 parts) and D-xylose (4 parts). Hydrolysis of the methylated material yielded methyl oleanolate and a mixture containing 2 : 3 : 4 : 6-tetra-, 3 : 4 : 6-tri-, and 2 : 4-di-*O*-methyl-D-glucose, and 2 : 3- and 2 : 4-di-*O*-methyl- and 2- and 3-*O*-methyl-D-xylose, with very small amounts of 2 : 3 : 4 : 6-tetra- and tri-*O*-methylgalactoses.

Degradation of the periodate-oxidised saponin with phenylhydrazine, followed by methylation and hydrolysis of the product, gave methyl oleanolate and 2 : 3 : 4-tri- and 2 : 3-di-*O*-methyl-D-xylose.

These results are discussed and compared with previous findings.

Mora gonggrijpii, a large tree occurring in the Guianas, produces the heavy and durable commercial timber, morabukea. It is often very difficult to distinguish this wood from that of the related species mora (*Mora excelsa*), but the materials used in the present investigation and in Part I * were all definitely identified as morabukea by a study of the herbarium material.

In Part I * the results of a preliminary investigation of the saponins (SI) from the heartwood of morabukea were reported. It was shown that D-galactose constituted 8·4% of the carbohydrate residue, the other components being D-glucose and D-xylose. A further preparation (Farmer and Campbell, *Nature*, 1950, **165**, 237) of the saponin (SII) from a different log, however, gave on hydrolysis only very small amounts of galactose. The second saponin sample has now been examined in detail.

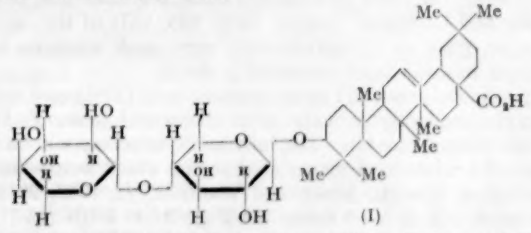
Hydrolysis of purified saponin SII gave oleanolic acid (37%) and a mixture of sugars. Quantitative paper chromatography of the latter (Hirst and Jones, *J.*, 1949, 1659) showed glucose (9 parts) and xylose (4 parts). The fully methylated saponin on hydrolysis yielded methyl oleanolate and a mixture of methylated sugars which were separated by partition on a column of cellulose (Hough, Jones, and Wadman, *J.*, 1949, 2511). The following materials were isolated: 2 : 3 : 4 : 6-tetra- (54·2%), 3 : 4 : 6-tri- (15·7%) and 2 : 4-di-*O*-methyl-D-glucose (2·1%), 2 : 3- (3·9%) and 2 : 4-di-*O*-methyl-D-xylose (2·3%), 2 : 3 : 4 : 6-tetra-*O*-methylgalactose (*ca* 0·3%) and tri-*O*-methylgalactoses (0·7%), and a mixture (20·7%) containing 2- and 3-*O*-methyl-D-xyloses in the ratio of 1 : 2. The tetra- and tri-*O*-methylglucoses and 2 : 4-di-*O*-methyl- and 2-*O*-methyl-xylose were obtained as crystalline

* Part I, *J.*, 1954, 752.

sugars, and 2 : 3-di-*O*-methyl- and 3-*O*-methyl-xylose yielded the corresponding crystalline aniline derivatives. The syrupy 2 : 4-di-*O*-methylglucose was identified by its R_G value, methoxyl content, demethylation to glucose, and by the formation of formaldehyde on periodate oxidation. Demethylation of the fractions corresponding in R_G value to tetra- and tri-*O*-methylgalactoses yielded galactose along with some glucose; because of the small amount of material available, however, these were not examined further. The proportions of the individual constituents of the mono-*O*-methylxylose fraction were established from the equilibrium rotation in water of the derived lactone mixture (cf. Part I, *loc. cit.*). Traces of free xylose were also identified among the hydrolysis products, though it is probable that this substance is an artifact arising from incomplete methylation of the saponin or from demethylation during hydrolysis. Similar considerations may well apply to the relatively small amount of di-*O*-methylglucose isolated.

As with the sample SI, it is evident that SII is a mixture. While these two preparations have, in general, similar compositions they vary considerably in structural detail. Thus, the oleanolic acid content (37%) of the sample SII is higher than that of SI (30%), the ratios of 2- to 3-*O*-methylxylose obtained on hydrolysis of the methylated derivatives differ (1 : 1 from SI and 1 : 2 from SII) and the proportion of galactose residues in SII is only a small fraction of that found in SI. Fractionation of the mixture of methylated sugars obtained on hydrolysis of the methylated saponin SI yielded, among other products, 2 : 4 : 6-tri-*O*-methyl-D-glucose (9·2%) and a smaller fraction (**3***a*; 0·5%) (Part I, *loc. cit.*) which was not further investigated but was probably 2 : 3 : 6- or 3 : 4 : 6-tri-*O*-methyl-D-glucose. The methylated material SII, on the other hand, furnished 3 : 4 : 6-tri-*O*-methyl-D-glucose (15·7%) with only very small amounts of other tri-*O*-methylglucoses. This sugar was obtained as the crystalline β-anomer and was identified by comparison with a synthetic specimen (Sundberg, McCloskey, Rees, and Coleman, *J. Amer. Chem. Soc.*, **1945**, **67**, 1080) kindly given by Dr. G. H. Coleman. Its isolation is of particular interest, as structures involving 1 : 2-linked glucose residues are uncommon in Nature, though their presence in the hemicellulose of Iceland moss (Granichstädten and Percival, *J.*, 1943, **54**), in crown-gall polysaccharide (Putman, Potter, Hodgson, and Hassid, *J. Amer. Chem. Soc.*, **1950**, **72**, 5024), in sophoraflavonoloside (Rabaté, *Bull. Soc. chim. France*, 1940, **7**, 565; Freudenberg, Knauber, and Cramer, *Chem. Ber.*, **1951**, **84**, 144), and in apiin (Hemming and Ollis, *Chem. and Ind.*, 1953, 85) has been established.

The saponin SII on periodate oxidation and degradation of the product with phenylhydrazine (Barry, *Nature*, **1943**, **152**, 537; Barry and Mitchell, *J.*, 1954, 4020 and references therein) yielded a material which, on hydrolysis, gave oleanolic acid and xylose, along with small amounts of glucose. Hydrolysis of the methylated degraded saponin gave methyl oleanolate, 2 : 3-di-*O*-methyl-D-xylose, and 2 : 3 : 4-tri-*O*-methyl-D-xylose with small amounts of other derivatives. The low $[\alpha]_D$ of the acetate of the degraded saponin suggests that the xylose residues are joined by β-linkages and the fragment (I) must be present in at least one component of the SII mixture.



(I)

In contrast to makoré saponin which was shown (King, Baker, and King, *J.*, 1955, 1338) to have a 6-sulphato-ester group attached in the glucose residue, the saponin SII contains no sulphur.

The above results have demonstrated the constitutional variability of the saponin, and, while the general nature of the product is apparent, more precise information regarding its composition must await the development of efficient fractionation procedures; the methods

tried so far proved unsuccessful. Paper chromatography (cf. Dutta, *Nature*, 1955, **175**, 85; King *et al.*, *loc. cit.*) has, as yet, failed to give any clear-cut separation of the constituents.

Experimental

General experimental directions are given in Part I (*loc. cit.*). Paper partition chromatography was carried out on Whatman No. 1 filter paper, unless otherwise stated, and the following solvent systems (v/v; top layer) were used: (A) butanol–ethanol–water–ammonia (40 : 10 : 49 : 1); (B) benzene–butanol–pyridine–water (1 : 5 : 3 : 3); (C) ethyl acetate–acetic acid–water (3 : 1 : 3); (D) pentanol–acetic acid–water (4 : 1 : 5); and (E) benzene–ethanol–water (169 : 47 : 15). All qualitative chromatograms were run in the presence of authentic specimens of the appropriate sugars.

The saponin was prepared from a sample of the heartwood of morabukea as described earlier (Farmer and Campbell, *loc. cit.*) (Found: S, nil). Hydrolysis of the product with ethanolic hydrogen chloride yielded crystalline oleanolic acid, m. p. and mixed m. p. 303°.

The saponin (20 g.) gave an acetate (24·5 g.), $[\alpha]_D^{19}$ −13° (*c*, 1·0 in $CHCl_3$) (Found: Ac, 38·4%). These constants were unchanged by further acetylation. Attempts to fractionate the product by stepwise precipitation or solution were unsuccessful.

The acetate (9 .g) was treated with 0·4N-sodium hydroxide at room temperature and yielded a purified saponin (4·8 g.) which was used in the following investigations.

Hydrolysis with Sulphuric Acid.—The purified saponin was heated at 100° with N-sulphuric acid for 7 hr. and gave oleanolic acid (37·0%) which was removed. The filtrate was neutralised and evaporated to dryness. Examination of the residue on the paper chromatogram [solvents (B) and (C)] indicated the presence of glucose and xylose, with very small amounts of galactose. A quantitative estimation (Hirst and Jones, *loc. cit.*) gave glucose (9 parts) and xylose (4 parts).

Methylation.—Methylation of the acetate (10·5 g.) with methyl sulphate and sodium hydroxide followed by treatment with methyl iodide and silver oxide gave a fully methylated product (6·3 g.), $[\alpha]_D^{19}$ −10° (*c*, 2·01 in $CHCl_3$) (Found: OMe, 32·8%).

Methanolysis, Hydrolysis, and Fractionation.—The methylated saponin (5·8 g.) was heated with methanolic 3% hydrogen chloride (300 c.c.) under reflux for 5½ hr. and the solution was neutralised with silver carbonate, filtered, and evaporated to dryness. The residue was heated with N-sulphuric acid (200 c.c.) at 100° for 9 hr. (rotation constant). Methyl oleanolate (1·9 g.) was removed and after recrystallisation from methanol had m. p. and mixed m. p. 196° (Found: OMe, 6·0. Calc. for $C_{31}H_{50}O_3$: OMe, 6·6%). The filtrate was neutralised with barium carbonate, filtered, and evaporated to dryness. Extraction of the residue with boiling acetone gave a mixture of methylated sugars (3·6 g.). This mixture (3·10 g.) was fractionated on a column of cellulose (Hough, Jones, and Wadman, *loc. cit.*) with butanol–light petroleum (b. p. 100—120°) (2 : 3) saturated with water as eluant to give fractions (1) 1·4358 g., (2) 0·0134 g., (3) 0·5806 g., (4) 0·0168 g., (5) 0·0210 g., (6) 0·0787 g., and (7) 0·5041 g. (recovery, 2·6504 g., 85·5%).

Fractions (3) and (6) were mixtures. Fraction (3) was refractionated on a column of cellulose as above, to give (3*a*) 0·2734 g., (3*b*) 0·1153 g., and (3*c*) 0·0460 g. Separation of a portion of (3*b*) on 3MM paper (solvent A) gave (3*bi*) 0·0185 g. and (3*bii*) 0·0382 g. Fraction (3*bi*) was combined with (3*a*).

Fractionation of material (6) on 3MM paper as above gave fractions (6*a*) 0·0197 g. and (6*b*) 0·0268 g. The former was combined with fraction (5), and the latter with fraction (7).

Fraction (1). This had R_G 1·00 and crystallised completely to give 2 : 3 : 4 : 6-tetra-*O*-methyl-D-glucose, m. p. and mixed m. p. 94°, $[\alpha]_D^{19}$ +98° (5 min.), +87° (1 hr.), +81° (24 hr., const.) (*c*, 1·1 in H_2O) (Found: C, 51·0; H, 8·5; OMe, 52·0. Calc. for $C_{10}H_{20}O_6$: C, 50·8; H, 8·5; OMe, 52·5%).

Fraction (2). This had the same R_G value as tetra-*O*-methylgalactopyranose. Demethylation (Hough, Jones, and Wadman, *J.*, 1950, 1702) gave galactose and glucose, identified on the paper chromatogram (solvent B). The R_G value indicated that the glucose component was 2 : 3 : 4-tri-*O*-methylglucose.

Fraction (3a). The fraction was freed from traces of impurity by further chromatography on a column of cellulose as before, with butanol–light petroleum (b. p. 100—120°) (3 : 7) saturated with water as eluant. The product crystallised completely and on recrystallisation from ether had m. p. and mixed m. p. 95—96°, $[\alpha]_D^{18}$ +45° (5 min.), +50° (15 min.), +63° (1 hr.), +73° (4 hr.), +79° (24 hr., const.) (*c*, 0·985 in H_2O) (Found: C, 48·3; H, 8·0; OMe, 40·8. Calc. for $C_9H_{18}O_6$: C, 48·6; H, 8·2; OMe, 41·9%). Hypoiodite oxidation (Hirst, McGilvray, and Percival, *J.*, 1950, 1297) indicated 97% of tri-*O*-methylaldose. Complete methylation gave

tetra-*O*-methyl-D-glucose, m. p. and mixed m. p. 91°, R_G 1·00. Periodate oxidation in phosphate buffer (Bell, *J.*, 1948, 992) gave no formaldehyde, while oxidation with metaperiodate (Greville and Northcote, *J.*, 1952, 1945) yielded 0·98 equiv. of volatile acid. Repeated attempts to prepare a crystalline aniline derivative were unsuccessful.

The material was compared on the chromatogram with authentic 3 : 4 : 6-tri-*O*-methyl-D-glucose (αβ-mixture; kindly supplied by Dr. G. D. Greville), and showed identical behaviour in the three solvents used. In solvents A and D it travelled at the same rate as 2 : 3 : 6-tri-*O*-methylglucose and faster than 2 : 4 : 6-tri-*O*-methylglucose. In solvent E it moved 22·4 cm. while the 2 : 3 : 6-derivative travelled 18·0 cm. overnight.

Fraction (3*bii*). This had the same R_G value as 2 : 3-di-*O*-methylxylose and $[\alpha]_D^{19}$ +25° (*c*, 0·48 in H_2O). The syrup (16·6 mg.) on periodate oxidation yielded formaldehyde, identified as the dimedone compound (22 mg.), m. p. and mixed m. p. 184°. The aniline derivative had m. p. 121—123° (Found : OMe, 22·7. Calc. for $C_{13}H_{19}O_4N$: OMe, 24·5%).

Fraction (3*c*). This travelled on the chromatogram at the same rate as 2 : 4-di-*O*-methylxylose and crystallised completely to give 2 : 4-di-*O*-methyl-β-D-xylose, m. p. and mixed m.p. 105° (Found : C, 47·0; H, 7·9; OMe, 33·4. Calc. for $C_7H_{14}O_5$: C, 47·2; H, 7·9; OMe, 34·8%).

Fraction (4). This gave on demethylation galactose and very small amounts of glucose identified on the paper chromatogram (solvent B).

Fraction (5). This had the same R_G value as 2 : 4-di-*O*-methylglucose (solvent D; travelled 27·3 cm.; both 2 : 3- and 3 : 4-di-*O*-methylglucose travelled 32·2 cm. in 3 days at 23°) (Found : OMe, 28·1. Calc. for $C_8H_{16}O_6$: OMe, 29·8%). Demethylation yielded glucose only. The syrup, on periodate oxidation, gave formaldehyde, identified as the dimedone compound, m. p. and mixed m. p. 180°.

Fraction (7). The syrup (OMe, 17·2%) did not crystallise. Fraction (7) (0·4536 g.) was dissolved in ethanol and the solution was evaporated slowly to small volume in a vacuum-desiccator. The crystals which separated (37 mg.) had m. p. 138°, unchanged on admixture with 2-*O*-methyl-D-xylose (Found : C, 44·2; H, 7·5; OMe, 18·5. Calc. for $C_6H_{12}O_5$: C, 43·9; H, 7·4; OMe, 18·9%). Evaporation of the residual solution gave a syrup (0·3727 g.) which was examined by paper ionophoresis (cf. Foster, *J.*, 1953, 982) on Whatman No. 1 filter sheet at 400 v in borate buffer (pH 9·97). Both 2- and 3-*O*-methylxylose were detected (the complexes travelled 7·8 and 13 cm. respectively in 6 hr.).

The syrup on treatment with aniline gave 3-*O*-methyl-*N*-phenyl-D-xylosylamine, m. p. and mixed m. p. 137° (Found : OMe, 13·1; N, 6·1. Calc. for $C_{12}H_{17}O_4N$: OMe, 12·9; N, 5·9%).

Oxidation of the syrup with bromine yielded a syrupy lactone having $[\alpha]_D^{18}$ +73° (6 hr.), +69° (76 hr.), +55° (295 hr.), +50° (504 hr., const.) (*c*, 0·974 in H_2O) (13·56 mg. required 4·11 c.c. 0·0202N-sodium hydroxide for neutralisation. Calc. for $C_6H_{10}O_5$: 4·14 c.c.).

Treatment of the lactones with methanolic ammonia gave the corresponding amides. The syrupy mixture with alkaline hypochlorite and semicarbazide hydrochloride (Weerman, *Rec. Trav. chim.*, 1917, **37**, 16) yielded hydrazodicarbonamide, m. p. and mixed m. p. 256°.

Periodate Oxidation and Degradation with Phenylhydrazine.—Saponin (9 g.) was dissolved in water (400 c.c.), sodium metaperiodate (30 g.) was added, and the solution was kept in the dark for 8 days (periodate consumption complete). Excess of periodate was destroyed by the addition of ethylene glycol and the solution was dialysed in a Cellophane bag till free from iodate (1 week). The solution was evaporated to *ca.* 200 c.c. and used without further treatment for the degradation.

To the above solution phenylhydrazine (60 g.) was added, followed by sufficient acetic acid to clarify the solution. The mixture was left for 14 days at room temperature in the dark and was then heated for ½ hr. in a boiling-water bath. After 24 hr. the solid material was separated by filtration, washed quickly with water, ethanol, and ether and dried in a vacuum-desiccator (yield, 2·8 g.).

Acetylation of the Degradation Product.—The solid was acetylated with pyridine and acetic anhydride, and the acetate recovered by precipitation with water. It was dissolved in acetone, and the solution dried (Na_2SO_4), evaporated to small volume, and poured into light petroleum (b. p. 80—100°) to yield a precipitate (2·2 g.), $[\alpha]_D^{16}$ +8° (*c*, 0·5 in acetone) (Found : Ac, 26·2%). Evaporation of the residual solution gave a brown syrup (0·3 g.) which was not examined further.

Deacetylation.—Deacetylation of the saponin acetate. The acetate (0·55 g.) of the degraded saponin was dissolved in acetone (100 c.c.), and 0·4N-sodium hydroxide (100 c.c.) added. The solution was left overnight and then diluted to 1 l. with water. Ions were removed by columns of resins and the solution was evaporated to dryness. The residue was dissolved in ethanol, the

solution filtered, and the filtrate evaporated to dryness to give a syrup (0·41 g.). Hydrolysis of this material with N-sulphuric acid gave xylose and a small amount of glucose, identified on the paper chromatogram, along with an insoluble residue.

Methylation.—The acetate (1·6 g.) of the degraded saponin was methylated, first with sodium hydroxide and methyl sulphate and then with silver oxide and methyl iodide in the usual manner. This gave a syrupy methylated derivative (1·23 g.) (Found : OMe, 14·4%, unchanged on further methylation).

Hydrolysis and Fractionation.—The foregoing syrup (1·05 g.) was heated in methanolic 3% hydrogen chloride (150 c.c.) under reflux for 7 hr., and the solution was neutralised with silver carbonate and filtered. The filtrate was evaporated to dryness and the residue heated with N-sulphuric acid (200 c.c.) for 9 hr. at 100°. The brown tar was separated by filtration and, after several recrystallisations from methanol, yielded methyl oleanolate, m. p. and mixed m. p. 188—189°. The filtrate was neutralised with barium carbonate and evaporated to dryness to give a syrup (0·2 g.). Examination on the chromatogram (solvent A) indicated the presence of 2 : 3 : 4-tri- and 2 : 3-di-*O*-methylxylose as the main constituents with small amounts of 2 : 4-di- and mono-*O*-methylxylose and tri-*O*-methylglucose. The mixture of methylated sugars was separated on a column of cellulose (16″ × 1″) as before to give fractions (*a*) 45·8 mg., (*b*) 54·8 mg., and (*c*) 11·8 mg.

Fraction (*a*). This had the same R_G value as 2 : 3 : 4-tri-*O*-methylxylose (solvents A, D, and E) and gave a pink spot with aniline oxalate. The brown syrup was purified by chromatography on sheets of Whatman No. 1 paper (solvent A), but the product did not crystallise. Rehydrolysis with N-sulphuric acid and examination of the product on the chromatogram revealed only one spot, showing the absence of contaminating methyl 2 : 3-di-*O*-methylxylosides in fraction (*a*).

Fraction (*b*). This was a mixture containing 2 : 3-di-*O*-methylxylose with small amounts of what appeared to be tri-*O*-methylglucose. The xylose derivative was separated by sheet chromatography with butanol–light petroleum (b. p. 100—120°) (3 : 7) saturated with water as solvent, and with aniline in ethanol yielded 2 : 3-di-*O*-methyl-*N*-phenyl-D-xylopyranosylamine, m. p. 110—112°; the mixed m. p. with an authentic specimen (m. p. 121—123°) was 118—120°.

Fraction (*c*). This had the same R_G value as 2- or 3-*O*-methylxylose and was not further investigated.

Paper Chromatography of Saponin SII.—Chromatograms were run with several solvents but in no case was separation satisfactory. The position of the saponin on the paper was established by spraying with the periodate and then with the borax–boric acid–potassium iodide–starch reagents of Metzenberg and Mitchell (*J. Amer. Chem. Soc.*, 1954, **76**, 4187), the saponin being revealed as a pale elongated spot against a blue background. The best results were obtained with Whatman 3MM paper and butanol–acetic acid–water (4 : 1 : 5, v/v; top layer) as solvent. By the use of reference strips the zone containing the saponin was located and cut out. This was divided laterally into two equal portions, and the saponin in each was eluted and hydrolysed. Both fractions yielded glucose and xylose in approximately the same proportions.

The faster-moving saponin could be freed from traces of free sugars by partition on a column of cellulose; the product obtained in this manner was a very pale, non-reducing amorphous solid.

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SECTION OF CHEMISTRY, FOREST PRODUCTS RESEARCH LABORATORY,
PRINCES RISBOROUGH, AYLESBURY, BUCKS. [*Received, June 21st*, 1955.]

A Glycosidic Constituent of Vinca minor *and its Identification as 3-β-D-Glucosyloxy-2-hydroxybenzoic Acid.*

By F. E. King, J. H. Gilks, and M. W. Partridge.

[Reprint Order No. 6534.]

A new glycoside, hydrolysed to 2 : 3-dihydroxybenzoic acid and D-glucose, has been found in methanolic extracts from the leaves of *Vinca minor*. It has been identified as 3-β-D-glucosyloxy-2-hydroxybenzoic acid by a synthesis of the methyl ester penta-acetate; in addition, the glucosylation of 2 : 4- and of 3 : 4-dihydroxybenzoic acid has been investigated.

Other constituents obtained from the leaves include ursolic acid, independently observed by Le Men and Pourrat (*Ann. pharm. franç.*, 1952, **10**, 349; 1953, **11**, 449), and an alkaloid $C_{21}H_{26}O_3N_2$, which appears to be identical with vincamine described by Schlittler and Furlenmeier (*Helv. Chim. Acta*, 1953, **36**, 2017).

The genus *Vinca* or periwinkle (fam. Apocynaceae), which is widely distributed in Europe and Western Asia, embraces the evergreen trailing plants *V. minor* and *V. major*, and decoctions of the leaves of these species have long been known to possess astringent and carminative properties. Tannins and a syrupy "glucoside" have been found in the leaves of *V. minor* (Rutishauser, *Bull. Sci. Pharmacol.*, 1932, **39**, 475; *Compt. rend.*, 1932, **195**, 75), and the occurrence of alkaloids in certain *Vinca* species has been reported, *e.g.*, in *V. pubescens*, believed to be identical with *V. major*, from which three crystalline bases of unknown constitution have been obtained (Orekhoff, Gurevich, Norkina, and Prein, *Arch. Pharm.*, 1934, **272**, 70). A further product, present in the flowers of both *V. minor* and *V. major*, is the glycoside robinin, kæmpferol 7-L-rhamnosido-3-robinoside, which has previously been isolated from *Robinia pseudacacia* (Zemplén and Bognár, *Ber.*, 1941, **74**, 1783). This summarises the principal features of the chemistry of the genus prior to a further examination in 1951—53 (J. H. Gilks, Thesis, Nottingham, April, 1954) of the constituents of *V. minor* leaves derived from commercial sources. Other independent contemporary investigations are mentioned in the following account of our work.

The macerated dry leaves and attached stems were extracted with boiling methanol, and after concentration of the resulting solution to small bulk, a dark green solid separated, which was purified by extensive recrystallisation. The eventually colourless product, m. p. 287—290°, gave a positive response to the Liebermann–Burchardt test, and analyses of a rigorously dried specimen indicated a molecular formula of $C_{30}H_{46(48)}O_3$. With aqueous sodium hydroxide a sparingly soluble salt was obtained which reacted with methyl sulphate to give a methyl ester. The compound was thus recognised as a triterpene carboxylic acid and its conversion by acetic anhydride with basic catalysts into a monoacetate established the alcoholic function of the remaining oxygen atom. With perchloric acid as catalyst, however, a crystalline product containing two acetyl residues was obtained which, as it formed with aqueous ethanol a monoacetate, is apparently the monoacetate mixed anhydride. A comparison of the physical constants of the acid and of its derivatives with those of the relevant known triterpenes indicated a possible identity with ursolic acid. This was confirmed by the preparation from authentic ursolic acid of the acetate and acetate-anhydride, of methyl ursolate, and of two new derivatives, *i.e.*, the benzoate and the highly crystalline acetoacetate, the latter from the toluene-*p*-sulphonic acid-catalysed reaction with diketen. Moreover, an account of the distribution of ursolic acid published after the conclusion of these experiments (Le Men and Pourrat, *Ann. pharm. franç.*, 1952, **10**, 349; 1953, **11**, 449) records the isolation of the triterpene from nine *Apocynaceae*, including *V. minor* and *V. major*.

By stirring with dilute hydrochloric acid an evaporated methanol extract prepared from a mixture of the leaves and calcium hydroxide, a solution of the basic constituents

was obtained, from which chloroform removed a crude alkaloid hydrochloride. Treatment of the chloroform solution with alkali yielded a weakly basic product, eventual m. p. 230—231°, of molecular formula $C_{21}H_{26}O_3N_2$, having a picrate, m. p. 228—229°. The base contains one methoxyl group, and the ultraviolet absorption (max. at 228 and 276 mμ) resembles that of alkaloids of the indole group. It clearly corresponds to the alkaloid vincamine, $C_{21}H_{26}O_3N_2$, m. p. 232—233° (picrate, m. p. 220—225°), $\lambda_{max.}$ 230, 278 mμ, shortly afterwards reported by Schlittler and Furlenmeier (*Helv. Chim. Acta*, **1953**, **36**, 2017) as a constituent of *V. minor*.

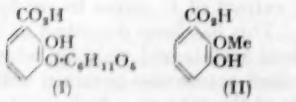
An examination was also undertaken of the methanolic extract of *V. minor* leaves for the so-called glucoside described by Rutishauser (*loc. cit.*). This has been described as a syrupy material precipitated as a lead derivative by basic lead acetate and yielding, when acid-hydrolysed, 2 : 3-dihydroxybenzoic acid and an unspecified ketose also obtained with protocatechuic acid from the amorphous tannin constituents of the extract. A chromatographic analysis of the water-soluble residues after the precipitation of tannins and removal of excess of lead acetate disclosed the presence of fructose and sucrose, and of two phenolic substances, one giving a green ferric colour attributed to residual tannins, and the other an intense violet. The latter compound was precipitated as a heavy yellow complex with basic lead acetate as described by Rutishauer, but when recovered from the lead derivative it was still contaminated with tannins. Accordingly, aqueous solutions of the syrup were chromatographed on columns of powdered cellulose with butanol–ethanol–water as developing solvent, whereupon the glycoside was obtained as a pale brown viscous syrup (0·3% of the dried leaves) which gradually became partly crystalline and slowly liberated carbon dioxide from aqueous sodium hydrogen carbonate. However, the method was tediously slow, and it was found more expedient, although resulting in a slightly impure product, to employ the ion-exchange resin ' Deacidite E ' and to liberate the absorbed glycoside by washing the resin with ammonia, ' Zeo-Karb 215 ' being used to liberate the glycoside from its ammonium salt. From neither process was the compound obtained in a substantially crystalline form although further investigation proved that the material isolated by chromatography on the cellulose was free from observable impurity.

Hydrolysis of the glycoside with boiling dilute sulphuric acid and extraction with ethyl acetate gave 2 : 3-dihydroxybenzoic acid, m. p. 206—207° (decomp.), identical with a specimen synthesised from *o*-vanillin by methylation and oxidation of the product to *o*-veratric acid which was then demethylated with boiling hydrobromic acid. From the carbohydrate remaining in the sulphuric acid solution phenyl-D-glucosazone was obtained and it was shown by paper chromatography that, of the three hexoses from which the osazone could have been derived, only D-glucose was formed during the hydrolysis. The yields of the two hydrolytic products were not inconsistent with the view that the parent substance was a monoglucoside, its intense ferric reaction favouring structure (I) in which the 3-position is the site of the glucosyloxy-group.

Evidence bearing on the supposed orientation of the glucose residue was found in the failure of the phenolic group to react with diazomethane, thereby indicating its chelated condition and hence its proximity to the carboxylic substituent. Methylation with methyl sulphate and aqueous alkali (Haworth, *J.*, 1915, **107**, 8), however, caused hydrolysis of the glucosyloxy-group and the formation of 2 : 3-dimethoxybenzoic acid. This is no doubt due to prior methylation of the 2-position since it has been observed by Fisher, Hawkins, and Hibbert (*J. Amer. Chem. Soc.*, **1941**, **63**, 3031) that *o*-methoxyaryl glycosides are unusually sensitive to hydrolytic agents.

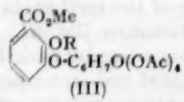
The syrupy ester obtained from the glucoside and diazomethane was exhaustively methylated with methyl iodide and silver oxide (Purdie and Irvine, *J.*, **1903**, **83**, 1021). The non-crystalline product, which no longer possessed a ferric reaction, was subjected to acid hydrolysis, whence the isolation of the previously unknown 3-hydroxy-2-methoxybenzoic acid (II) left no doubt as to the orientation of the glucose residue. A crystalline derivative, the methyl ester penta-acetate, m. p. 165—166°, was obtained by treating the glucoside with acetic anhydride–sodium acetate followed by diazomethane. Its constitution (III; R = Ac), and hence that of the natural compound, was confirmed by a synthesis from α-tetra-acetobromo-D-glucose and methyl 2 : 3-dihydroxybenzoate; acetylation of

the product yielded a pure methyl ester penta-acetate, m. p. 169°, mixed m. p. 165—168°, which in view of its preparation from the α-acetobromoglucose is presumed to be a β-glucoside. Infrared absorption measurements, for which we thank Mr. M. St. C. Flett, Imperial Chemical Industries Limited, show the very close resemblance of the synthetic and the natural product, slight variations being attributable to impurities in the natural sample. *X*-Ray powder diagrams were prepared by Dr. S. C. Wallwork and they confirm the relationship of the two specimens.



(I)

(II)



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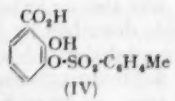

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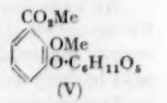


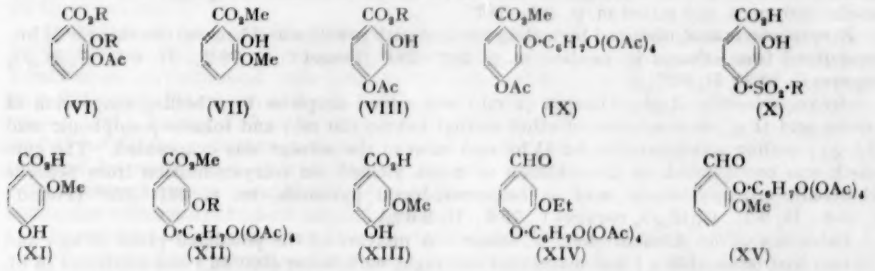
(V)

Although the superior reactivity of the 3-hydroxyl group in 2 : 3-dihydroxybenzoic acid leaves little doubt that direct glucosidation will result in a 3-substituted product, some attention was nevertheless given to a possible unambiguous synthesis of the natural glucoside or of a crystalline derivative thereof. A desirable intermediate for this purpose is 2-hydroxy-3-toluene-*p*-sulphonyloxybenzoic acid (IV) since after methylation at the 2-position and hydrolysis of the toluenesulphonyl group it permits of a synthesis of a homogeneous 3-glucoside. The required compound (IV) was readily obtained by the toluenesulphonation of 2 : 3-dihydroxybenzoic acid in aqueous alkali but, under similar conditions, methyl 2 : 3-dihydroxybenzoate gave a mixture of the mono- and di-toluene-*p*-sulphonates, the mono-compound being identical with that prepared from (IV) with methanolic hydrogen chloride. When this ester was methylated with methyl iodide–potassium carbonate, methyl 2-methoxy-3-toluene-*p*-sulphonyloxybenzoate was obtained which was hydrolysed with alkali to 3-hydroxy-2-methoxybenzoic acid (II). The latter had m. p. 151—152° which was depressed by the isomeric 2-hydroxy-3-methoxybenzoic acid, m. p. 152°, and gave no colour with ferric chloride. 2-Ethoxy-3-hydroxybenzoic acid was prepared analogously and also *via* the 3-methanesulphonyl derivative. The methyl ester of 3-hydroxy-2-methoxybenzoic acid was a liquid which reacted with α-tetra-acetylbromoglucose to form the crystalline methyl 3-β-tetra-acetyl-D-glucosyloxy-2-methoxybenzoate (III; R = Me). Deacetylation in methanolic hydrogen chloride yielded methyl 3-β-D-glucosyloxy-2-methoxybenzoate (V), m. p. 187—189°. However, failure to restrict methylation to the 2-position of the natural glucoside prevented its identification by means of this purely synthetic compound.

Other derivatives of 2 : 3-dihydroxybenzoic acid were prepared in order to investigate the glucosidation of this acid at the 2-position. Thus acetylation with acetic anhydride–sodium acetate under conditions used by Lesser and Gad (*Ber.*, 1926, **59**, 233) for the preparation of 4-acetoxy-2-hydroxybenzoic acid, or by Chattaway's process (*J.*, 1931, 2495), gave 3-acetoxy-2-hydroxybenzoic acid (VI; R = H). Methylation of this acid (VI; R = H) gave the 2-methyl ether with, however, some replacement of the acetyl group. Thereafter, hydrolysis to 3-hydroxy-2-methoxybenzoic acid (II) proved that acetylation had occurred in the 3-position. Esterification, therefore, of the acid (VI; R = H) with diazomethane afforded methyl 3-acetoxy-2-hydroxybenzoate which, however, combined with α-tetra-acetylbromo-D-glucose in quinoline with silver oxide to a syrupy product. A non-crystalline substance was formed under similar conditions from methyl 2-hydroxy-3-methoxybenzoate (VII), the latter being prepared either by esterification of the acid with diazomethane or from 2 : 3-dihydroxybenzoic acid with methyl sulphate–potassium carbonate in acetone.

The synthetical experiments were extended to the isomeric 2 : 4- and 3 : 4-dihydroxybenzoic acid. It is known that monoacetylation of the former acid gives 4-acetoxy-2-hydroxybenzoic acid (VIII; R = H) (Lesser and Gad, *loc. cit.*); and a sample of this derivative prepared by Chattaway's method was esterified with diazomethane. The resulting ester (VIII; R = Me) was combined with α-tetra-acetylbromo-D-glucose in the usual way, but the product remained a syrup; analysis indicated its composition to be

substantially that of methyl 4-acetoxy-2-β-tetra-acetyl-D-glucosyloxybenzoate (IX). A comparable synthesis from 2-hydroxy-4-methanesulphonyloxybenzoic acid (X; R = Me) which was esterified and then glucosylated, also gave a syrup after treatment with methanolic sodium methoxide (Zemplén and Pacsu, *Ber.*, 1929, **62**, 1613), possibly owing to incomplete removal of the methanesulphonyl protecting group. The orientation of the latter substituent in (X; R = Me) was established by methylation to the methoxy-ester and hydrolysis, the known 4-hydroxy-2-methoxybenzoic acid (XI) being obtained. Similarly it was proved that the monotoluenesulphonation product of 2 : 4-dihydroxybenzoic acid was the 4-substituted derivative (X; R = C_6H_4Me).



Finally, the monoglucoside of methyl 3 : 4-dihydroxybenzoate prepared by Mauthner (*J. prakt. Chem.*, 1915, **91**, 174) and presumed by him to be the 4-glucoside (XII; R = H) has been decisively oriented. Methylation of the methyl tetra-acetylglucosyloxy-hydroxybenzoate to a monomethyl ether (XII; R = Me) obtained by Mauthner (*ibid.*, 1911, **83**, 556) was followed by hydrolysis to 4-hydroxy-3-methoxybenzoic acid (XIII), thus confirming the structure tentatively assigned to the glucoside.

A five-step synthesis of 3-glucosyloxy-4-hydroxybenzaldehyde due to Helferich and Papalambrou (*Annalen*, 1942, **551**, 242) appeared to offer the prospect of a route to the analogous acid glucosides by simple oxidation of the aldehyde group. Trial oxidation experiments were therefore conducted with the more readily available 3-ethoxy-4-tetra-acetylglucosyloxy- and 3-methoxy-2-tetra-acetylglucosyloxy-benzaldehyde (XIV) and (XV), the latter prepared from 2-hydroxy-3-methoxybenzaldehyde. However, these aldehydes failed to undergo oxidation under the necessarily mild conditions employed, or gave non-crystalline neutral products, presumably owing to incipient destruction of the carbohydrate substituent.

Experimental

Extraction of Ursolic Acid from Vinca *Species.*—The finely powdered leaves and stems of *V. minor* (2 kg.) were continuously extracted with boiling aqueous methanol (90%) for 24 hr. The dark green, amorphous solid (25 g.) which separated from the concentrated extract was partly purified by treatment with charcoal in boiling glacial acetic acid and by digestion with acetone, with light petroleum (b. p. 60—80°), and with benzene. By repeated treatment with charcoal in boiling ethanol, this material eventually furnished crude, amorphous ursolic acid, m. p. 268—271°, which on being digested with boiling ethanol was obtained as colourless needles (8 g., 0·4%), m. p. 287—290° (undepressed on admixture with authentic ursolic acid), $[\alpha]_D^{20}$ + 67·0° (*c* 0·68 in *iso*propanol), + 68·4° (*c* 1·49 in dioxan) (Goodson, *J.*, 1938, 999, records $[\alpha]_D^{21}$ + 67·5°) [Found, in material dried at 150°/vac.: C, 78·8; H, 10·9; active H, 0·4%; *M* (Rast), 433. Calc. for $C_{30}H_{48}O_3$: C, 78·9; H, 10·5; 2 active H, 0·4%; *M*, 456]. *V. major* similarly afforded 0·53% of ursolic acid.

The methyl ester had m. p. 167—168°, undepressed on admixture with an authentic specimen (Sell and Kremers, *J. Biol. Chem.*, 1938, **126**, 501).

Acetylursolic Acid.—A solution of the acid (1 g.) in *iso*propenyl acetate (11 ml.) and concentrated sulphuric acid (1 drop) was boiled for 3 hr., concentrated, and diluted with ether. The

crystalline residue from the acid-free ethereal solution gave, on recrystallisation from light petroleum, pure acetylursolic acid (0·3 g.), m. p. 285—288°, undepressed by an authentic specimen (Sando, *J. Biol. Chem.*, 1931, **90**, 477) (Found: C, 77·1; H, 10·0; OAc, 7·8. Calc. for $C_{32}H_{50}O_4$: C, 77·1; H, 10·0; OAc, 8·6%).

Acetylursolic Acetic Anhydride.—Ursolic acid (1 g.) dissolved in a mixture of acetic anhydride (10 ml.) and aqueous perchloric acid (60%; 3 drops) on being kept for 2 hr. The brown gum (1·05 g.), precipitated by the addition of water, furnished on crystallisation from light petroleum the mixed anhydride, m. p. 197—198°, with resolidification and melting at 306—308° (decomp.), undepressed by a specimen prepared by the method of Sando (*loc. cit.*) [Found: C, 75·7; H, 9·2; OAc, 13·1%; *M* (*X*-ray), 532. Calc. for $C_{34}H_{52}O_5$: C, 75·6; H, 9·6; 2OAc, 15·4%; *M*, 540]. On being boiled in aqueous ethanol (70%) for 5 hr., this compound afforded acetylursolic acid, m. p. and mixed m. p. 285—287°.

Benzoylursolic acid, obtained by boiling the acid with pyridine and benzoyl chloride for 2½ hr., crystallised from ethanol in needles, m. p. 282—284° (Found: C, 79·2; H, 9·4. $C_{37}H_{52}O_4$ requires C, 79·3; H, 9·3%).

Acetoacetylursolic Acid.—Diketen (4 ml.) was added dropwise to a boiling suspension of ursolic acid (1 g.) in a mixture of ethyl methyl ketone (50 ml.) and toluene-*p*-sulphonic acid (0·5 g.); boiling was continued for 1½ hr. and most of the solvent was evaporated. The gum which was precipitated on the addition of water yielded, on recrystallisation from benzene (charcoal), *acetoacetylursolic acid* as hexagonal-based pyramids, m. p. 221—222° (Found: C, 75·6; H, 9·7. $C_{34}H_{52}O_5$ requires C, 75·6; H, 9·6%).

Extraction of the Alkaloids from V. minor.—A mixture of the powdered plant (2 kg.) and calcium hydroxide (150 g.) was macerated overnight with water (500 ml.) and methanol (6 l.), and refluxed for 6 hr. Extraction with successive quantities of boiling methanol (4·5 l.) was continued until no more methanol-soluble material was extracted. Solvent was removed from these extracts and the residue was boiled for 5 min. with sufficient 2N-hydrochloric acid to render the mixture acid to Congo-red, allowed to cool, and kept at 0° for 24 hr. Alkaloid was removed from the acid-insoluble residue by repeated washing with water. The combined aqueous solutions were concentrated, partially decolorised with kieselguhr, and exhaustively extracted with chloroform. Basic material (4 g.), recovered from the aqueous liquid, failed to yield any pure compound. The chloroform solution on being evaporated afforded a dark brown gum from which crude bases (1·25 g.) were recovered by extraction with hot water and precipitation with sodium hydroxide. The *alkaloid*, m. p. 214—217° (0·15 g., 0·0075%), was eventually obtained as golden needles, m. p. 230—231°, from methanol [Found: C, 70·7; H, 7·5; N, 7·7; OMe, 8·7%; *M* (Rast), 344. $C_{21}H_{26}O_3N_2$ requires C, 71·1; H, 7·4; N, 7·9; OMe, 8·7%; *M*, 354]; light absorption in EtOH: max. at 228 (ε 29,160) and 276 mμ (ε 8213). Its *picrate*, obtained by treatment of a solution of the alkaloid in aqueous lactic acid with sodium picrate, had m. p. 228—229°, after crystallisation from aqueous methanol (Found: C, 55·1; H, 5·4; N, 12·0; OMe, 5·5. $C_{27}H_{29}O_{10}N_5$ requires C, 55·6; H, 5·0; N, 12·0; OMe, 5·3%).

Isolation of the Glucoside from V. minor.—The mother-liquor from the isolation of ursolic acid was concentrated under reduced pressure, kept for 24 hr., filtered, and concentrated to a viscous, red syrup; this was dissolved in methanol and poured into acetone. Tannins were partly removed from an aqueous solution of the precipitate by means of lead acetate. The syrupy product recovered after removal of the excess of lead with hydrogen sulphide was shown by paper chromatography to contain tannins, sucrose, fructose, and the required glucoside.

The paper chromatogram was irrigated during 64 hr. with the upper layer obtained by shaking together butanol, ethanol, and water (4 : 1 : 5). After being dried, the spots were located on separate strips by using aniline phthalate, naphtharesorcinol–trichloroacetic acid, and 2% ferric chloride. All four components responded to the carbohydrate reagents; in addition the tannins afforded a green colour, and the glucoside a violet colour with ferric chloride. The identities of the sucrose and the fructose were established by direct chromatographic comparison with authentic specimens.

The glucoside and tannins were separated from the sugars as their insoluble lead salts, formed on the addition of solution of basic lead acetate, and regenerated by means of hydrogen sulphide in glacial acetic acid; the resulting amorphous solid (13 g.) could not be further purified by means of solvents or by precipitation of the acidic glucoside as a salt.

Accordingly, the mixture was fractionated chromatographically on cellulose (Hough, Jones, and Wadman, *J.*, 1949, 2511) with butanol–ethanol–water (4 : 1 : 5) as developing solvent; the course of fractionation was followed by means of ferric chloride reagent. Fractions corresponding to the elution of a pale pink band from the column, on concentration, afforded an

extremely hygroscopic syrup which eventually partly crystallised (yield from 112 g. of plant material, 0·35 g., 0·3%). This material behaved as a homogeneous substance on paper chromatography.

In the ion-exchange method, an aqueous solution of the acetone-precipitated mixture from 2 kg. of plant was passed down a column of basic " Deacidite E " (250 g.). Colouring matter was removed from the column by irrigation with water, and the glucoside was recovered by treatment with dilute solution of ammonia. The effluent was concentrated to a small volume, adjusted to pH 7, filtered, and passed through a column of acid " Zeo-Karb 215 " (250 g.). The syrup (12—15 g.) obtained on concentration of the effluent and drying the ethanol-soluble fraction *in vacuo* over phosphoric oxide consisted of the resinous glucoside (1·2—2·3 g.) slightly contaminated with tannins. By seeding with cystalline glucoside, this material was obtained partly crystalline.

Hydrolysis of the Glucoside.—The syrupy glucoside (0·35 g.) was boiled for 3 hr. with 2·5N-sulphuric acid; the residue obtained on evaporating an ethyl acetate extract of this solution furnished on crystallisation from water 2 : 3-dihydroxybenzoic acid (0·1 g.), m. p. and mixed m. p. 206—207° (Found : C, 54·8; H, 4·0%; equiv., 155. Calc. for $C_7H_6O_4$: C, 54·4; H, 3·9%; equiv., 154). Methyl 2 : 3-dimethoxybenzoate, prepared from this acid by interaction with methyl iodide and potassium carbonate in acetone, had m. p. 47°, undepressed by a sample prepared by methylation of 2 : 3-dimethoxybenzoic acid with diazomethane. On treatment with diazomethane the isolated acid afforded its methyl ester, m. p. 80—81°, undepressed on admixture with methyl 2 : 3-dihydroxybenzoate.

The aqueous liquid remaining from the hydrolysis was neutralised with barium carbonate and examined for the presence of sugars by chromatography; direct comparison with glucose, fructose, and mannose revealed the presence of glucose alone. The osazone (0·07 g.) had the characters of phenyl-D-glucosazone, m. p. 204—205° (decomp.).

2 : 3-*Dihydroxybenzoic Acid.*—*o*-Vanillin (8 g.) was methylated by refluxing (36 hr.) it with methyl iodide (20 ml.) and potassium carbonate (10 g.) in acetone (150 ml.). The resulting 2 : 3-dimethoxybenzaldehyde (7 g., 80%; m. p. 50—52°) was oxidised in 97% yield to the corresponding acid by the procedure of Edwards, Perkin, and Stoyle (*J.*, 1925, **127**, 195). This acid (20 g.) when boiled (3 hr.) with hydrobromic acid (47%, 160 ml.) furnished 2 : 3-dihydroxybenzoic acid (13 g., 77%), m. p. 204—206° (decomp.), raised to 206—207° (decomp.) on recrystallisation from water. Its *p-chlorobenzamidinium salt* separated from aqueous ethanol as rods, m. p. 238—239° (decomp.) (Found : C, 54·6; H, 4·4; N, 8·5. $C_{14}H_{13}O_4N_2Cl$ requires C, 54·4; H, 4·2; N, 9·1%). Its *monobenzoyl ester* crystallised from aqueous acetone as plates, m. p. 212—213° (Found : C, 64·9; H, 4·2%; equiv., 262. $C_{14}H_{10}O_5$ requires C, 65·1; H, 3·9%; equiv., 258); this compound is considered to be 3-benzoyloxy-2-hydroxybenzoic acid, since in ethanol it afforded a violet colour with ferric chloride.

Methylation of the Glucoside.—(i) Methylation by Haworth's method (*loc. cit.*) afforded 2 : 3-dimethoxybenzoic acid, m. p. 122—123°, as the only isolable product (Found : equiv., 187. Calc. for $C_9H_{10}O_4$: equiv., 182).

(ii) On the addition of a large excess of an ethereal solution of diazomethane to a methanolic solution of the glucoside, solid separated immediately; removal of the solvent from the suspension which had been kept at 0° for 24 hr. furnished a syrup. Four such treatments failed to yield material no longer responding to the ferric reaction.

(iii) Dry material (4·7 g.) from the foregoing experiment was refluxed in dry methanol (100 ml.) with methyl iodide (36 g.), dry silver oxide (22 g.) being added gradually during 5 hr.; this methylation was repeated five times. The filtered reaction mixture gave no colour with ferric chloride but resisted all attempts to obtain a crystalline product from it. Accordingly the product (4·1 g.) in methanol (25 ml.) was refluxed for 5 hr. with 5N-sulphuric acid (50 ml.), and freed from tar by filtration. An ethyl acetate extract of the filtrate furnished 3-*hydroxy*-2-*methoxybenzoic acid* (II) (0·15 g.) which crystallised from water as needles, m. p. 151—152°, undepressed on admixture with a specimen prepared as described below (Found : C, 57·0; H, 4·8. $C_8H_8O_4$ requires C, 57·1; H, 4·8%).

Acetylation of the Glucoside.—The mixture obtained by refluxing the glucoside (2 g.) with acetic anhydride (50 ml.) and sodium acetate (5 g.) for 1 hr. afforded a semi-solid precipitate on being poured into water. Since no crystalline product could be recovered from this material, it was treated with diazomethane; the crystals (0·054 g.; m. p. 158—160°) which slowly separated from the concentrated reaction mixture yielded, on recrystallisation from methanol, *methyl* 2-*acetoxy*-3-β-*tetra-acetyl*-D-*glucosyloxybenzoate* (III; R = Ac) (0·03 g.) as colourless prisms, m. p. 165—166°; the mixed m. p. with a synthetic specimen (see below), of m. p. 169°, was

165—168°. The identity of these two specimens was confirmed by infrared absorption measurements and *X*-ray powder diagrams.

Methyl 2 : 3-Dihydroxybenzoate.—(i) A solution of 2 : 3-dihydroxybenzoic acid (8 g.) in dry methanol (150 ml.) was saturated with dry hydrogen chloride, boiled for 12 hr., cooled, again saturated with hydrogen chloride, and boiled for 24 hr. The ester (6 g.), isolated by evaporation of most of the solvent, treatment with aqueous sodium hydrogen carbonate and extraction with ether, crystallised from aqueous methanol as needles, m. p. 80—81° (Found: C, 57·1; H, 4·8. Calc. for $C_8H_8O_4$: C, 57·1; H, 4·8%); in D.-R.P. 281,214 the m. p. is reported to be 75—78°.

(ii) A suspension of the sodium salt, made from the acid (15·4 g.) and sodium (2·3 g.) in methanol (30 ml.) and water (15 ml.), when refluxed for 36 hr. with excess of methyl iodide afforded the ester (7 g.), m. p. and mixed m. p. 78—81°.

Methyl 2-Acetoxy-3-β-tetra-acetyl-D-glucosyloxybenzoate (III; R = Ac).—A cold mixture of methyl 2 : 3-dihydroxybenzoate (3 g.), α-acetobromo-D-glucose (8 g.), sodium hydroxide (0·7 g.), acetone (30 ml.), and water (15 ml.) was shaken for 5 hr. The syrup (2·1 g.) remaining after evaporation of the solvent and removal of alkali failed to crystallise. It was boiled with acetic anhydride (100 ml.) and sodium acetate (10 g.) for 1 hr., and poured into water. The semi-solid precipitate was dried by azeotropic distillation with benzene, and covered with dry light petroleum. The crystals which had formed during 5 months were rapidly collected after the addition of a small quantity of ice-cold ethanol, and obtained from ethanol as prisms (0·25 g.), m. p. 169°, $[\alpha]_D^{20}$ −28·3° (*c* 2·02 in acetone) (Found: C, 53·6; H, 5·5; OMe, 6·3; OAc, 39·2. $C_{24}H_{32}O_{14}$ requires C, 53·4; H, 5·2; OMe, 5·7; 5OAc, 39·8%).

2-Hydroxy-3-toluene-p-sulphonyloxybenzoic Acid (IV).—When prepared by warming 2 : 3-dihydroxybenzoic acid (2·9 g.) with toluene-*p*-sulphonyl chloride (3·6 g.) and sodium hydroxide (1·6 g.) in aqueous acetone for 10 min. and acidifying, this *acid* crystallised from aqueous ethanol as plates, m. p. 176—178° (Found: C, 54·6; H, 4·0. $C_{14}H_{12}O_6S$ requires C, 54·4; H, 3·9%). In ethanol solution, it yielded a violet colour with ferric chloride.

The foregoing acid (5·45 g.) was esterified with methanol as described for methyl 2 : 3-dihydroxybenzoate. The *methyl ester* (5 g.) crystallised from methanol as prisms, m. p. 87—88° (Found: C, 55·7; H, 4·5. $C_{15}H_{14}O_6S$ requires C, 55·9; H, 4·3%).

Interaction of Methyl 2 : 3-Dihydroxybenzoate and Toluene-p-sulphonyl Chloride.—The ester (1·3 g.) was shaken with sodium hydroxide (0·4 g.) and toluene-*p*-sulphonyl chloride (1·4 g.) in aqueous acetone for 10 min. A solution of the solid product in ethanol and dilute hydrochloric acid deposited *methyl 2 : 3-di(toluene-p-sulphonyloxy)benzoate*, which after recrystallisation from acetone–propan-2-ol, was obtained as prisms (0·3 g.), m. p. 133—135° (Found: C, 55·3; H, 4·4; S, 13·1. $C_{28}H_{26}O_8S_2$ requires C, 55·6; H, 4·2; S, 13·5%). From the acidified ethanolic mother-liquor, methyl 2-hydroxy-3-toluene-*p*-sulphonyloxybenzoate (0·7 g.), m. p. and mixed m. p. 87—88°, was recovered.

Methyl 2-Methoxy-3-toluene-p-sulphonyloxybenzoate.—This *ester* was produced when 2-hydroxy-3-toluene-*p*-sulphonyloxybenzoic acid (12·3 g.) was boiled with an excess of methyl iodide and anhydrous potassium carbonate (10 g.) in acetone (200 ml.) for 48 hr., and crystallised from methanol as prisms, m. p. 77—78° (12·5 g.) (Found: C, 57·6; H, 5·0; OMe, 18·7. $C_{16}H_{16}O_6S$ requires C, 57·2; H, 4·8; 2OMe, 18·5%).

3-Hydroxy-2-methoxybenzoic Acid (II).—Methyl 2-methoxy-3-toluene-*p*-sulphonyloxybenzoate (12 g.) was refluxed for 48 hr. with sodium hydroxide (2·9 g.) in aqueous acetone (270 ml.), and part of the solvent was distilled off. The material which separated after acidification furnished *2-methoxy-3-toluene-p-sulphonyloxybenzoic acid* (5·4 g.), which crystallised from aqueous methanol as plates, m. p. 132—133° (Found: C, 55·8; H, 4·5; OMe, 9·5. $C_{15}H_{14}O_6S$ requires C, 55·9; H, 4·3; OMe, 9·6%). By extraction of the acid mother-liquor with ethyl acetate there was obtained *3-hydroxy-2-methoxybenzoic acid* (3 g.), which crystallised from water as rods, m. p. 151—152°, depressed to 122—123° on admixture with 2-hydroxy-3-methoxybenzoic acid (Found: C, 57·0; H, 5·0; OMe, 18·3%; equiv., 166. $C_8H_8O_4$ requires C, 57·1; H, 4·8; OMe, 18·5%; equiv., 168). Its *salt* with *p*-chlorobenzamidine had m. p. 243° (decomp.) (Found: C, 56·0; H, 4·3. $C_{15}H_{15}O_4N_2Cl$ requires C, 55·8; H, 4·6%). On methylation with methyl iodide–potassium carbonate, the acid furnished methyl 2 : 3-dimethoxybenzoate, m. p. and mixed m. p. 47°. Demethylation by boiling (½ hr.) hydrobromic acid afforded 2 : 3-dihydroxybenzoic acid, m. p. and mixed m. p. 206—207° (decomp.).

When the hydrolysis was effected with 2N-sodium hydroxide, the reaction was complete in 3½ hr., and the required acid was obtained in 93% yield. 3-Hydroxy-2-methoxybenzoic acid gave no colour with ferric chloride.

Methyl 3-*hydroxy*-2-*methoxybenzoate*, prepared from 3-hydroxy-2-methoxybenzoic acid by the procedure described for methyl 2 : 3-dihydroxybenzoate, had b. p. 146—148°/12—13 mm., n_D^{20} 1·5337 (Found : C, 59·1; H, 5·8; OMe, 34·1. $C_9H_{10}O_4$ requires C, 59·3; H, 5·5; 2OMe, 34·1%).

Methyl 2-*Methoxy*-3-β-*tetra-acetyl*-D-*glucosyloxybenzoate* (III; R = Me).—The foregoing ester (0·85 g.), dry quinoline (10 ml.), α-acetobromo-D-glucose (8 g.), and dry silver oxide (3 g.) were shaken together for 1 hr., kept for 1 hr. and treated with glacial acetic acid (40 ml.). The suspension was filtered and the filtrate poured into ice-cold water (200 ml.). Recrystallisation of the precipitate (2 g.) first from methanol and then from propan-2-ol afforded *methyl* 2-*methoxy*-3-β-*tetra-acetyl*-D-*glucosyloxybenzoate* (1·4 g.) as needles, m. p. 119—120°, $[\alpha]_D^{20}$ −35·0° (*c* 2 in acetone) (Found : C, 53·7; H, 5·8; OMe, 12·4; OAc, 32·2. $C_{23}H_{28}O_{13}$ requires C, 53·9; H, 5·5; 2OMe, 12·1; 4OAc, 33·6%).

Methyl 3-β-D-*glucosyloxy*-2-*methoxybenzoate* (V) was obtained by shaking a suspension of its tetra-acetyl derivative (4 g.) in dry methanolic hydrogen chloride (1%; 50 ml.) for 24 hr.; the resulting homogeneous solution was adjusted to pH 4·5 by the cautious addition of sodium. Most of the solvent was removed and the *methyl* 3-β-D-*glucosyloxy*-2-*methoxybenzoate* (1·5 g.) which crystallised as needles was purified by recrystallisation from methanol; it had m. p. 187—189°, $[\alpha]_D^{20}$ −53·8° (*c* 1·01 in MeOH) (Found : C, 52·3; H, 5·7; OMe, 17·5. $C_{15}H_{20}O_9$ requires C, 52·3; H, 5·8; 2OMe, 18·0%).

Ethyl 2-*Ethoxy*-3-*toluene*-p-*sulphonyloxybenzoate*.—This *ester* was prepared in 73% yield by the method described for the corresponding methyl ester methyl ether and formed prisms, m. p. 64—65°, from methanol (Found : C, 58·9; H, 5·4; OEt, 26·2. $C_{18}H_{20}O_6S$ requires C, 59·2; H, 5·5; 2OEt, 25·3%). When refluxed for 3 hr. with 2N-sodium hydroxide in acetone, it afforded 2-*ethoxy*-3-*hydroxybenzoic acid* which crystallised from water as prisms, m. p. 130—131° (Found : C, 59·5; H, 5·6; OEt, 25·0%; equiv., 179. $C_9H_{10}O_4$ requires C, 59·3; H, 5·5; OEt, 24·8%; equiv., 182); this acid gave no colour with ferric chloride. Its p-*chlorobenzimidinium salt*, m. p. 217° (decomp.), crystallised from water as flat elongated prisms (Found : C, 56·8; H, 4·7; N, 7·9. $C_{16}H_{17}O_4N_2Cl$ requires C, 57·1; H, 5·0; N, 8·3%).

2-*Acetoxy*-3-*toluene*-p-*sulphonyloxybenzoic Acid*.—The phenolic acid (1 g.) and sodium acetate (2·5 g.) in acetic anhydride (25 ml.) when heated on a steam-bath for 1 hr. afforded its *acetyl ester* (0·6 g.), which crystallised from benzene–light petroleum as needles, m. p. 149° (Found : C, 54·8; H, 4·1. $C_{16}H_{14}O_7S$ requires C, 54·8; H, 4·0%).

Methyl 2-*Hydroxy*-3-*methanesulphonyloxybenzoate*.—2-*Hydroxy*-3-*methanesulphonyloxybenzoic acid*, prepared in 73% yield as described for the corresponding toluene-*p*-sulphonyl ester, crystallised from water as elongated flat prisms, m. p. 158—159° (Found : C, 41·4; H, 3·8%; equiv., 232. $C_8H_8O_6S$ requires C, 41·4; H, 3·5%; equiv., 232); this compound gave a violet colour with ferric chloride. On treatment with diazomethane, it afforded its *methyl ester*, elongated prisms, m. p. 110—111° (from aqueous methanol) (Found : C, 44·1; H, 4·3; OMe, 13·4. $C_9H_{10}O_6S$ requires C, 43·9; H, 4·0; OMe, 12·6%). With ferric chloride, an ethanolic solution gave a ruby-red colour.

3-*Methanesulphonyloxy*-2-*methoxybenzoic Acid*.—3-Hydroxy-2-methoxybenzoic acid (1·7 g.) and sodium hydroxide (0·9 g.) in water (25 ml.) and methanesulphonyl chloride (0·9 ml.) were shaken together for 15 min., kept for 30 min., and acidified. The precipitate yielded 3-*methanesulphonyloxy*-2-*methoxybenzoic acid* (2·1 g.) as prisms, m. p. 126—127° when crystallised from water (Found : C, 44·2; H, 3·8. $C_9H_{10}O_6S$ requires C, 43·9; H, 4·1%).

Ethyl 2-*Ethoxy*-3-*methanesulphonyloxybenzoate*.—This *compound* (2·2 g.) was obtained by boiling the phenolic acid (2·25 g.), potassium carbonate (6 g.), and ethyl iodide (4 g.) in acetone (50 ml.) for 24 hr. and occurred as a viscous liquid, b. p. 142°/0·1 mm., $n_D^{20\cdot5}$ 1·5066 (Found : C, 50·4; H, 5·9. $C_{12}H_{16}O_6S$ requires C, 50·0; H, 5·6%). The ester (1·3 g.) in propan-2-ol (15 ml.) was heated on a steam-bath for 1 hr. with sodium hydroxide (0·2 g., 1 mol.) in water (15 ml.). The precipitate obtained on acidification furnished 2-*ethoxy*-3-*methanesulphonyloxybenzoic acid* (0·8 g.) as needles, m. p. 116—117°, when crystallised from water (Found : C, 46·2; H, 4·8. $C_{10}H_{12}O_6S$ requires C, 46·2; H, 4·6%). When the quantity of sodium hydroxide was increased to 3 mols., and the heating prolonged for 2 hr., the product was 2-ethoxy-3-hydroxybenzoic acid.

3-*Acetoxy*-2-*hydroxybenzoic acid* (VI; R = H) was prepared in 55% yield from 2 : 3-dihydroxybenzoic acid by the procedure of Lesser and Gad (*loc. cit.*) and by that of Chattaway (*loc. cit.*) in 82% yield; it crystallised as prisms, m. p. 135—137°, from benzene or hydrated needles, m. p. 85°, from water (Found : C, 55·0; H, 4·2%; equiv., 197. $C_9H_8O_5$ requires C, 55·1; H, 4·0; equiv., 196. Found in hydrated material : loss, 9·1. $C_9H_8O_5,H_2O$ requires

H_2O, 8·4%). On methylation with diazomethane, the acid (4·2 g.) afforded *methyl 3-acetoxy-2-hydroxybenzoate* (3·8 g.), which crystallised from light petroleum (b. p. 60—80°) as prisms, m. p. 70—71°, b. p. 102—104°/0·1 mm., $n_D^{20\cdot5}$ 1·5243 (Found: C, 56·9; H, 4·8; OMe, 14·4. $C_{10}H_{10}O_5$ requires C, 57·2; H, 4·8; OMe, 14·8%). Both these compounds gave a violet ferric reaction. Alkylation by the methyl iodide–potassium carbonate method yielded *methyl 3-acetoxy-2-methoxybenzoate* (VI; R = Me), b. p. 162—164°/13—14 mm. (Found: C, 59·3; H, 5·5. $C_{11}H_{12}O_5$ requires C, 58·9; H, 5·9%); this on hydrolysis with sodium hydroxide in aqueous acetone gave 3-hydroxy-2-methoxybenzoic acid, m. p. 150—152°.

Attempted Glucosidation of Methyl 3-Acetoxy-2-hydroxybenzoate.—A mixture of the ester (2·1 g.), α-acetobromo-D-glucose (8·5 g.), silver oxide (6 g.), and quinoline (10 ml.) was shaken for 1 hr., and kept overnight. The water-insoluble material obtained after removal of the silver compounds was a syrup which did not crystallise.

Methyl 2-Hydroxy-3-methoxybenzoate (VII).—2-Hydroxy-3-methoxybenzoic acid (Perkin and Stoyle, *J.*, 1923, **123**, 3171) with excess of diazomethane afforded methyl 2-hydroxy-3-methoxybenzoate, m. p. 67—68° (lit., 67—68°), in 74% yield. Treatment of 2 : 3-dihydroxybenzoic acid (1 g.) with methyl sulphate (1·7 g.) in dry acetone (20 ml.) and benzene (80 ml.) in the presence of potassium carbonate (4 g.) gave a 19% yield (Found: C, 59·2; H, 5·7; OMe, 33·7. Calc. for $C_9H_{10}O_4$: C, 59·3; H, 5·5; 2OMe, 34·0%).

Attempted Glucosidation of Methyl 2-Hydroxy-3-methoxybenzoate.—The phenolic ester (0·9 g.), α-acetobromo-D-glucose (8 g.), silver oxide (3 g.), and quinoline (10 ml.) were shaken together for 1 hr., and then kept for 1 hr. The product obtained on working up in the usual way was a syrup.

Methyl 4-acetoxy-2-hydroxybenzoate (VIII; R = Me) was prepared by methylation with diazomethane of 4-acetoxy-2-hydroxybenzoic acid (VIII; R = H) which had been obtained by the method of Lesser and Gad (*loc. cit.*) or in 81% yield by Chattaway's procedure (*loc. cit.*); it crystallised from aqueous methanol as silky needles, m. p. 51—52° (Found: C, 57·0; H, 4·7; OAc, 22·6. $C_{10}H_{10}O_5$ requires C, 57·2; H, 4·8; OAc, 20·5%). On glucosidation by the acetobromoglucose–silver oxide–quinoline method, this compound afforded impure methyl 4-acetoxy-2-β-tetra-acetyl-D-glucosyloxybenzoate (IX) as a viscous syrup which failed to crystallise; the syrup was analysed after prolonged drying *in vacuo* over phosphoric oxide (Found: C, 52·8; H, 5·8. Calc. for $C_{24}H_{28}O_{14}$: C, 53·4; H, 5·2%).

2-Hydroxy-4-toluene-p-sulphonyloxybenzoic Acid (X; R = C_6H_4Me).—This *acid* was obtained when 2 : 4-dihydroxybenzoic acid was treated as described for its 2 : 3-isomer; on crystallisation from aqueous methanol, it formed prisms, m. p. 184—185° (Found: C, 54·8; H, 4·0. $C_{14}H_{12}O_6S$ requires C, 54·6; H, 3·9%). Methylation with methyl iodide for 48 hr. gave *methyl 2-methoxy-4-toluene-p-sulphonyloxybenzoate*, prisms, m. p. 56—57° (from aqueous propan-2-ol) (Found: C, 57·4; H, 4·7; OMe, 17·8. $C_{16}H_{16}O_6S$ requires C, 57·2; H, 4·8; 2OMe, 18·5%). Hydrolysis of this compound with an equivalent of sodium hydroxide gave *2-methoxy-4-toluene-p-sulphonyloxybenzoic acid*, plates, m. p. 133—134° (from aqueous methanol) (Found: C, 56·1; H, 4·6; OMe, 9·7. $C_{15}H_{14}O_6S$ requires C, 55·9; H, 4·3; OMe, 9·6%); with 3 equivalents of alkali, the hydrolysis product was 4-hydroxy-2-methoxybenzoic acid, m. p. 188—189° (decomp.): Bergmann and Dangschat (*Ber.*, 1919, **52**, 383) record m. p. 187—189° (decomp.).

Methyl 2-hydroxy-4-toluene-p-sulphonyloxybenzoate was produced on methylation of the acid (X; R = C_6H_4Me) with diazomethane and crystallised from ethanol–light petroleum as prisms, m. p. 88—89° (Found: C, 56·0; H, 4·0; OMe, 9·2. $C_{15}H_{14}O_6S$ requires C, 55·9; H, 4·3; OMe, 9·6%).

2-Hydroxy-4-methanesulphonyloxybenzoic Acid (X; R = Me).—Prepared in 74% yield from 2 : 4-dihydroxybenzoic acid as described above for the isomeric compound, this *acid* crystallised rom water as elongated, flat prisms, m. p. 175° (Found: C, 41·1; H, 3·6%; equiv., 236. $C_8H_8O_6S$ requires C, 41·4; H, 3·5%; equiv., 232). With diazomethane, it furnished its *methyl ester*, which crystallised from propan-2-ol as elongated prisms, m. p. 96—97° (Found: C, 43·9; H, 4·2; OMe, 12·4. $C_9H_{10}O_6S$ requires C, 43·9; H, 4·0; OMe, 12·6%).

Methyl 4-Methanesulphonyloxy-2-methoxybenzoate.—The foregoing acid, methylated by the methyl iodide–potassium carbonate method (24 hours' heating), furnished *methyl 4-methanesulphonyloxy-2-methoxybenzoate* (77%), b. p. 158°/0·1 mm., n_D^{20} 1·5365 (Found: C, 46·3; H, 4·7; OMe, 24·1. $C_{10}H_{12}O_6S$ requires C, 46·2; H, 4·6; 2OMe, 23·8%). When boiled for 15 min. with an equivalent of sodium hydroxide in aqueous propan-2-ol, this yielded *4-methanesulphonyloxy-2-methoxybenzoic acid*, which separated from water as needles, m. p. 169° (Found: C, 44·0; H, 3·8; OMe, 13·0. $C_9H_{10}O_6S$ requires C, 43·9; H, 4·1; OMe, 12·6%). When hydrolysis was effected with three equivalents of sodium hydroxide, the product was 4-hydroxy-2-methoxybenzoic

acid (XI), m. p. 188—189° (decomp.) (lit., 187—189°) (Found : OMe, 19·0. $C_8H_8O_4$ requires OMe, 18·5%).

Methyl 4-Methanesulphonyloxy-2-β-tetra-acetyl-D-glucosyloxybenzoate.—Dry silver oxide (6 g.) was added to a mixture of methyl 2-hydroxy-4-methanesulphonyloxybenzoate (2·5 g.), α-acetobromo-D-glucose (9 g.) and dry quinoline (10 ml.); the mixture was shaken for 4 hr., diluted with glacial acetic acid, filtered and poured into ice-water. The precipitate furnished the *tetra-acetylglucoside* (3 g.) as needles, m. p. 157°, $[\alpha]_D^{19}$ −31·3° (*c* 2·2 in acetone) on crystallisation from propan-2-ol (Found : C, 48·2; H, 5·3; OMe, 5·3; OAc, 31·2. $C_{23}H_{28}O_{15}S$ requires C, 47·9; H, 4·9; OMe, 5·4; 4OAc, 29·9%). Attempts to hydrolyse this compound (Zemplén and Pacsu, *loc. cit.*) yielded a syrup which failed to crystallise.

Methyl 3-Methoxy-4-β-tetra-acetyl-D-glucosyloxybenzoate (XII; R = Me).—Methyl 3-hydroxy-4-β-tetra-acetyl-D-glucosyloxybenzoate (Mauthner, *J. prakt. Chem.*, 1915, **91**, 174) (2 g.) and anhydrous potassium carbonate (4 g.) in acetone (50 ml.) were boiled with an excess of methyl iodide for 24 hr. The filtrate from the reaction mixture was concentrated and stirred with water; the insoluble oil when collected in ether, recovered, and crystallised first from aqueous methanol and then from aqueous propan-2-ol gave the 3-methyl ether as needles, m. p. 141—142° (Found : C, 54·1; H, 5·1; OMe, 12·3; OAc, 31·1. Calc. for $C_{23}H_{28}O_{13}$: C, 53·9; H, 5·5; OMe, 12·1; 4OAc, 33·5%); Mauthner (*ibid.*, 1911, **83**, 556) records m. p. 144—145° for this compound. When hydrolysed by boiling for 3 hr. with 2·5N-sulphuric acid it afforded 4-hydroxy-3-methoxybenzoic acid (XIII), m. p. and mixed m. p. 208—209°.

3-Ethoxy-4-β-tetra-acetyl-D-glucosyloxybenzaldehyde (XIV).—3-Hydroxy-4-β-tetra-acetyl-D-glucosyloxybenzaldehyde (Helferich and Papalambrou, *loc. cit.*) (2 g.) was refluxed for 12 hr. with potassium carbonate and an excess of ethyl iodide in acetone (30 ml.); the oil remaining when the filtered reaction mixture was concentrated crystallised when stirred with water and afforded the *3-ethyl ether* as prisms, m. p. 111—113°, $[\alpha]_D^{21}$ −53·2°, on recrystallisation from propan-2-ol (Found : C, 55·5; H, 6·0; OEt, 8·5. $C_{23}H_{28}O_{13}$ requires C, 55·6; H, 5·6; OEt, 9·2%), and gave a 2 : 4-*dinitrophenylhydrazone*, m. p. 202—203° (Found : C, 50·7; H, 4·7; OAc, 29·6. $C_{29}H_{32}O_{15}N_4,C_2H_4O_2$ requires C, 50·7; H, 4·9; OAc, 29·2. Found, in material dried at 120°/vac.: C, 52·1, H, 5·0. $C_{29}H_{32}O_{15}N_4$ requires C, 51·7; H, 4·8%). This aldehyde was recovered unchanged after treatment with hydrogen peroxide in acetic acid. A syrupy product which was without action on sodium hydrogen carbonate was obtained when attempts were made to effect oxidation by potassium permanganate in acetone or by silver oxide (Delépine and Bonnet, *Compt. rend.*, 1909, **149**, 39).

3-Methoxy-2-β-tetra-acetyl-D-glucosyloxybenzaldehyde (XV) was prepared in 31% yield from 2-hydroxy-3-methoxybenzaldehyde by the procedure of Helferich and Papalambrou (*loc. cit.*) and crystallised from propan-2-ol as needles, m. p. 137—138°, $[\alpha]_D^{20}$ −3·5° (*c* 4·5 in acetone) (Found : C, 54·6; H, 5·5; OMe, 6·5. $C_{23}H_{28}O_{13}$ requires C, 54·8; H, 5·4; OMe, 6·4%). By the method of Robertson and Waters (*J.*, 1931, 1881), the yield was 35%. Attempts to oxidise this compound with potassium permanganate in acetone or with silver oxide afforded neutral syrups.

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Improvements in the Preparation of [9-^{14}C]*Fluorene and* [9-^{14}C]*Phenanthrene.*

By A. S. Harris, E. N. White, and D. McNeil.

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Improved syntheses of fluorene and phenanthrene labelled with ^{14}C give overall yields of 86% and 82% respectively. Clemmensen reduction of fluorenone yields fluoren-9-ol, fluorene, di-9-fluorenyl, bisdiphenylene-ethylene (di-9-fluorenylidene), and 9-diphenylene-9 : 10-dihydro-10-oxophenanthrene under various conditions.

Isotopic dilution offers the most attractive and in some cases the only possible method for the determination of individual components in a complex mixture such as coal tar. Before this technique can be used methods for the synthesis of the labelled component, preferably in high yield, must be established. Such syntheses for labelled fluorene and phenanthrene are described.

[9-^{14}C]Fluorene has been prepared by Ray and Geiser (*Cancer Res.*, **1950**, **10**, 616) who treated 2-diphenylylmagnesium iodide with [^{14}C]carbon dioxide and cyclised the product to [9-^{14}C]fluorenone. The ketone was reduced by Clemmensen's method, labelled fluorene being obtained in an overall yield of 37%. This synthesis has now been improved to give 86% yield.

Carboxylation of the Grignard reagent in a vacuum manifold gave consistently over 90% yields when the reaction was carried out in ether but not in ether–benzene. Fluorenone was best reduced by the Wolff–Kishner method without an alkaline catalyst which promotes the formation of di-9-fluorenyl. Although experiments in sealed tubes gave almost quantitative yields of the pure hydrocarbon, reduction in a high-boiling solvent was preferred where radioactive materials were involved. Mono-, di-, and tri-ethylene glycols were used, the first giving the best yields.

In the Clemmensen reduction of fluorenone with 7% hydrochloric acid and a short reaction time the main product was fluoren-9-ol, which on further reduction gave fluorene. This is interesting because reduction of ketones by this method does not normally proceed by way of the corresponding alcohols (Martin, " Organic Reactions," Chapman and Hall, London, 1942, Vol. I, p. 156). Longer reduction of fluorenone yielded fluorene (approx. 80%) and di-9-fluorenyl (approx. 20%), in agreement with Ritchie's result (*J. Proc. Roy. Soc. N.S.W.*, **1946**, **80**, 33). Bradlow and VanderWerf (*J. Amer. Chem. Soc.*, 1947, **69**, 1254), however, who used 25% acid and a smaller proportion of zinc, obtained mixtures of fluorene and low-melting 9-diphenylene-9 : 10-dihydro-10-oxophenanthrene. Repetition of their work showed that, in addition to these compounds, smaller quantities of di-9-fluorenyl and bisdiphenylene-ethylene were also formed. In view of these results it appears that fluorenone is initially converted into the 9-hydroxyfluorenyl radical which either is reduced directly or by way of fluoren-9-ol to fluorene or dimerises to form 9 : 9′-dihydroxydi-9-fluorenyl (fluorenopinacol). According to the acid concentration this is then reduced to di-9-fluorenyl or rearranges to the pinacolin, 9-diphenylene-9 : 10-dihydro-10-oxophenanthrene, reactions which were shown to occur on Clemmensen reduction of the pinacol.

[9-^{14}C]Phenanthrene has been prepared in 58% yield starting from [^{14}C]carbon dioxide and 9-fluorenyl sodium (Collins, *J. Amer. Chem. Soc.*, 1948, **70**, 2418; Calvin, " Isotopic Carbon," Chapman and Hall, London, 1949, p. 234). This yield has been increased to 82%, mainly by improvements in the preparation of fluorene-9-[^{14}C]carboxylic acid. Consistently, about 95% yields of the acid were obtained by using 9-fluorenyl-lithium instead of the sodium derivative. In addition the fluorenyl-lithium was more conveniently prepared, being obtained by treatment of fluorene with phenyl-lithium in ether. This rapid and quantitative reaction was preferred to Tucker and Whalley's use (*J.*, 1949, 50)

of *n*-butyl-lithium in light petroleum. The acid was then converted into labelled phenanthrene in a similar way to that described by Calvin (*op. cit.*).

Experimental

Diphenyl-2-[^{14}C]*carboxylic Acid.*—The carboxylation was carried out in a manifold similar to that described by Cox, Turner, and Warne (*J.*, 1950, 3167), which was initially evacuated to a pressure of a few microns. 2-Diphenylylmagnesium iodide (from 7 g. of 2-iododiphenyl) in ether (30 c.c.) at −60° was vigorously stirred and treated with carbon dioxide from concentrated sulphuric acid and barium [^{14}C]carbonate (0·245 g.; 0·987 mc). When absorption was complete, the Grignard reagent was allowed to react with carbon dioxide from inactive barium carbonate (3·70 g.). After the initial rapid absorption, the residual gas was transferred to the reaction vessel by liquid nitrogen and stirring was continued for several hours. The acid was isolated in the usual way as a white solid (3·72 g., 94% yield from total barium carbonate), m. p. 103—105°.

[9-^{14}C]*Fluorenone.*—The above acid (3·72 g.) and concentrated sulphuric acid (10 c.c.) were heated at 80° (20 min.) and the product was poured on ice. The mixture was made slightly alkaline with sodium hydroxide solution and extracted with ether, and the extract was washed with water, dried, and evaporated, to give the yellow ketone (3·21 g., 95% yield), m. p. 79—80°.

[9-^{14}C]*Fluorene.*—[9-^{14}C]Fluorenone (3·21 g.), 90% hydrazine hydrate (8 c.c.), and ethylene glycol (80 c.c.) were refluxed for 5 hr. The fluorene, most of which had sublimed into the condenser, was extracted with ether, and the solution was washed with dilute hydrochloric acid and water, dried, and evaporated, to give the labelled hydrocarbon (2·87 g., 97%), m. p. 112—114°; activity 50·5 mc/mole. This represents an overall radioactive " yield " of 88·5% on the active $BaCO_3$ used.

Clemmensen Reduction of Fluorenone.—(*a*) Fluorenone (2·56 g.) in ethanol (40 c.c.) was added in portions during ½ hr. to amalgamated zinc (45 g.) in boiling concentrated hydrochloric acid (13 c.c.) and water (5 c.c.). The yellow colour of the ketone rapidly disappeared and the mixture was refluxed for a further hour and then poured into water (200 c.c.). Ether-extraction gave a white solid (2·45 g.) which was chromatographed on alumina. Elution with light petroleum (b. p. 60—80°) yielded fluorene (0·7 g.), and benzene eluted crude fluoren-9-ol (1·7 g.) which from benzene–light petroleum formed prisms, m. p. and mixed m. p. 144—145°.

(*b*) Fluorenone (3 g.) in ethanol (75 c.c.) was added during 1 hr. to amalgamated zinc (75 g.) in boiling concentrated hydrochloric acid (21 c.c.) and water (9 c.c.), additional portions of acid (2·5 c.c.) being added after 2 hr. and 5 hr. Extraction with benzene gave a mixture (2·8 g.) which when chromatographed on alumina yielded fluorene (2·05 g.), m. p. 114—115°, followed by di-9-fluorenyl (0·5 g.), needles (from propan-1-ol), m. p. 245—246°.

(*c*) Fluorenone (4·5 g.), amalgamated zinc (10 g.), ethanol (10 c.c.), and concentrated hydrochloric acid (25 c.c.) were refluxed for 24 hr., additional acid (5 c.c.) being added after 16 hr. Benzene extracted an orange solid (3·9 g.) which when separated on alumina gave successively, fluorene (0·4 g.), m. p. and mixed m. p. 113—114°, bisdiphenylene-ethylene (0·3 g.), m. p. and mixed m. p. 191—192°, di-9-fluorenyl (0·9 g.), m. p. and mixed m. p. 245—246°, and 9-diphenylene-9 : 10-dihydro-10-oxophenanthrene (1·6 g.), m. p. 259—260°.

Clemmensen Reduction of Fluoren-9-ol.—Fluorenol (1 g.), amalgamated zinc (18 g.), concentrated hydrochloric acid (7 c.c.), ethanol (15 c.c.), and water (3 c.c.) were refluxed for 7 hr. Ether extraction afforded a white solid (0·82 g.) from which fluorene (0·55 g.), m. p. and mixed m. p. 113—114°, was obtained by chromatography, the remaining fractions being sticky solids.

Clemmensen Reduction of 9 : 9′-Dihydroxydi-9-fluorenyl.—(*a*) The dihydroxy-compound (3 g.), amalgamated zinc (13 g.), concentrated hydrochloric acid (33 g.), and ethanol (13 c.c.) were refluxed for 24 hr. Evaporation of the benzene extract of the product yielded *9-diphenylene-9 : 10-dihydro-10-oxophenanthrene* (2·6 g.), m. p. 255—257°, which recrystallised from chloroform–light petroleum as prisms, m. p. 261—262° (Found : C, 90·5; H, 4·7. $C_{26}H_{16}O$ requires C, 90·7; H, 4·7%). The infrared spectrum and m. p. and mixed m. p. were identical with those of a specimen prepared by Gomberg and Bachmann's method (*J. Amer. Chem. Soc.*, 1927, **49**, 253). Chromatography of the crystallisation residues yielded di-9-fluorenyl (0·1 g.).

(*b*) The dihydroxy-compound (3 g.), amalgamated zinc (35 g.), concentrated hydrochloric acid (10 c.c.), ethanol (40 c.c.), and water (4·5 c.c.) were refluxed for 8 hr., additional acid being added after 3 hr. and 6 hr. Extraction of the product with benzene gave a sticky solid (2·75 g.) which was chromatographed on alumina. Crystallisation of the fractions yielded di-9-fluorenyl

(1·3 g.), m. p. and mixed m. p. 245—246°, and 9-diphenylene-9 : 10-dihydro-10-oxophenanthrene (0·2 g.), m. p. 256—257°, mixed m. p. 258—259°.

Fluorene-9-[^{14}C]carboxylic Acid.—Phenyl-lithium, prepared from bromobenzene (8 g.) and lithium (0·8 g.) (Wittig, "Newer Methods of Preparative Organic Chemistry," Interscience, London, 1948, p. 576), in dry ether (50 c.c.), was added under nitrogen to fluorene (8·4 g.) in a flask attached to a vacuum manifold which was subsequently evacuated to a pressure of a few microns. The reaction was carried out at −60° in two stages, carbon dioxide being generated first from barium [^{14}C]carbonate (0·244 g., 0·984 mc) and then from inactive barium carbonate (3·71 g.). The gas was readily absorbed by the well-stirred orange mixture which became gradually paler. After the mixture had been stirred for several hours to ensure complete reaction, it was acidified with 2N-sulphuric acid. The ether-soluble material was washed with sodium carbonate solution, acidification of which gave the acid (4·01 g., 95% yield from total barium carbonate), m. p. 228—229°.

[9-^{14}C]*Phenanthrene.*—The above acid (4·01 g.) was converted into [9-^{14}C]phenanthrene as described by Calvin (*op. cit.*, p. 234), except that the intermediate 9-hydroxy[^{14}C]methylfluorene (prepared in 99% yield from the acid) was not chromatographed on alumina as there was evidence of slight dehydration to 9-methylenefluorene on the adsorbent. The product formed by Wagner rearrangement of the alcohol was purified by chromatography on alumina (1 in. × 18 in.). Development and elution with light petroleum (b. p. 60—80°) gave the labelled hydrocarbon (2·91 g., 89% yield from the alcohol, 82% from carbon dioxide), m. p. 93—95°; activity 50·2 mc/mole representing a radioactive "yield" of 83·5% on the active $BaCO_3$ used.

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A New Synthesis of (±)-5 : 8-Thioctic Acid.

By Alfred Campbell.

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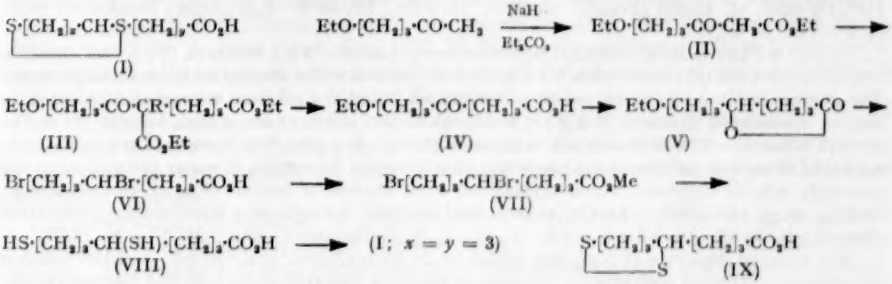
(±)-5 : 8-Thioctic acid (I) ($x = 3$; $y = 3$) has been synthesised from 5-ethoxypentan-2-one through 8-ethoxy-5-hydroxyoctanoic lactone (V) and methyl 5 : 8-dibromo-octanoate (VII).

For another investigation a pure sample of (±)-5 : 8-thioctic acid (I; $x = y = 3$), isomeric with the known growth factor for *Tetrahymena geleii*, (+)-6 : 8-thioctic acid (I; $x = 2$, $y = 4$), was required. The former acid has previously been synthesised (Reed, Hornberger, Heitmiller, Gunsalus, and Schnakenberg, *J. Amer. Chem. Soc.*, 1953, **75**, 1273; Bullock *et al.*, *ibid.*, 1952, **74**, 3455; 1954, **76**, 1828) but an element of ambiguity existed in the preparation (Reed *et al.*, *loc. cit.*) and a new approach was desirable.

Ethyl 6-ethoxy-3-oxohexanoate (II), prepared from 5-ethoxypentan-2-one with ethyl carbonate and sodium hydride (cf. La Forge and Gersdorf, *J. Amer. Chem. Soc.*, 1948, **70**, 3707), with ethyl acrylate gave diethyl α-(δ-ethoxybutyroyl)glutarate (III; R = H) in moderate yield, the main by-product being the bis-addition compound (III; R = $CH_2{\cdot}CH_2{\cdot}CO_2Et$). Acid hydrolysis and decarboxylation of the monoaddition product gave 8-ethoxy-5-oxo-octanoic acid (IV) which was reduced with potassium borohydride in alkaline solution to 8-ethoxy-5-hydroxyoctanoic lactone (V) in high yield. Attempts to convert this lactone into the dithiuronium salt in one stage, by reaction with thiourea and hydrogen bromide in a sealed tube (cf. Reed *et al.*, *loc. cit.*), were unsuccessful and the more circuitous route through 5 : 8-dibromo-octanoic acid (VI) had to be used. Consistently

high yields of the dibromo-acid were obtained by treatment of the ethoxy-lactone (V) with hydrogen bromide in glacial acetic acid, in the presence of concentrated sulphuric acid at room temperature and subsequently at 80° (Ames and Bowman, *J.*, 1951, 1079). The crude acid was esterified and the pure methyl ester (VII) obtained. Contrary to the experience of Reed *et al.* (*loc. cit.*) no evidence of lactonisation or rearrangement of the dibromo-ester (VII) was observed, the product appearing homogeneous in both its physical and subsequent chemical behaviour. The final stages of the synthesis, through the dithiuronium salt, were carried out substantially as described by Reed *et al.* (*loc. cit.*). The dithiuronium bromide could not be crystallised, but conversion into the dipicrate gave a high-melting material, which was readily crystallised. Alkaline hydrolysis of the corresponding dichloride gave 5 : 8-dimercapto-octanoic acid (VIII) which was cyclised to (±)-5 : 8-thioctic acid (IX) in poor yield.

Contrary to expectation, the (±)-5 : 8-thioctic acid did not give, in our hands, a positive sodium nitroprusside test for a thiol group in the presence of sodium cyanide. This



abnormal behaviour can presumably be attributed to the greater stability of the six-membered ring system, compared with the five-membered ring system in (±)-6 : 8-thioctic acid.

Experimental

Ethyl 6-Ethoxy-3-oxohexanoate.—5-Ethoxypentan-2-one (70 g.), b. p. 70—72°/10 mm. (Harradence and Lions, *J. Proc. Roy. Soc. New South Wales*, 1940, **74**, 159), in anhydrous ether (70 ml.) was added to a stirred suspension of powdered sodium hydride (26 g.) in anhydrous ether (200 ml.) and ethyl carbonate (200 g.), the rate of addition being adjusted to maintain a steady reflux. When the exothermic reaction had subsided, the mixture was refluxed for a further 2 hr. The excess of sodium hydride was then decomposed by the addition of absolute ethanol (5 ml.) and the mixture poured into an excess of dilute hydrochloric acid. The etheral phase was washed with 5% sodium hydrogen carbonate solution, dried, and fractionally distilled, to give *ethyl 6-ethoxy-3-oxohexanoate* (86 g., 79%), b. p. 89—91°/1 mm., n_D^{20} 1·4335 (Found: C, 59·5; H, 8·9. $C_{10}H_{18}O_4$ requires C, 59·4; H, 9·0%).

Ethyl α-(δ-Ethoxybutyroyl)glutarate.—Freshly distilled ethyl acrylate (14 g.) was added dropwise, during 1 hr., to a stirred solution of 10% alcoholic potassium hydroxide (5 ml.) in ethyl 6-ethoxy-3-oxohexanoate (50 g.) at 120° and the temperature kept thereat for a further hour. The mixture was poured into an excess of dilute hydrochloric acid and the product extracted with ether (4 × 100 ml.). Fractional distillation under reduced pressure gave the pure *glutarate* (39 g., 53·4%), b. p. 120—122°/0·2 mm., n_D^{21} 1·4441 (Found: C, 59·5; H, 8·7. $C_{18}H_{32}O_6$ requires C, 59·6; H, 8·7%), and *ethyl 8-ethoxy-4-ethoxycarbonyl-4-2′-ethoxycarbonylethyl-5-oxo-octanoate* (7 g.), b. p. 172—173°/0·2 mm., n_D^{20} 1·4534 (Found: C, 59·6; H, 8·4. $C_{20}H_{34}O_8$ requires C, 59·7; H, 8·5%).

8-Ethoxy-5-oxo-octanoic Acid.—Refluxing the foregoing diester (39 g.) with sulphuric acid (40 g.) in 50% w/w acetic acid (160 g.) for 2 hr. gave *8-ethoxy-5-oxo-octanoic acid* (22 g., 84·3%), b. p. 160°/0·1 mm., n_D^{20} 1·4545 (Found: C, 59·4; H, 8·8%; equiv., 201. $C_{10}H_{18}O_4$ requires C, 59·4; H, 9·0%; equiv., 202·2).

8-Ethoxy-5-hydroxyoctanoic Lactone.—An ice-cold solution of potassium borohydride (8 g.)

in water (50 ml.) was added portionwise to a cooled solution of 8-ethoxy-5-oxo-octanoic acid (22 g.) in 5N-sodium hydroxide (22 ml.) and the mixture set aside for 2 hr. at room temperature. After acidification, the crude lactone was extracted with ether (4 × 100 ml.). Fractional distillation of the combined, dried extracts gave *8-ethoxy-5-hydroxyoctanoic lactone* (12·5 g., 60·9%), b. p. 130—131°/1 mm., n_D^{20} 1·4591 (Found: C, 64·3; H, 9·5. $C_{10}H_{18}O_3$ requires C, 64·5; H, 9·7%).

Methyl 5 : 8-Dibromo-octanoate.—Concentrated sulphuric acid (12·5 ml.) was added dropwise to a stirred solution of the above lactone (5 g.) in 25% w/w hydrobromic acid in glacial acetic acid (250 ml.) at 10°. After 18 hr. at room temperature, the mixture was heated at 80° for 8 hr.; a further 10 ml. of 25% w/w hydrobromic acid in glacial acetic acid was added after 4 hr. The cooled, orange mixture was then poured on ice and the crude dibromo-acid extracted with ether (3 × 100 ml.). The combined, dried ethereal extracts were decolorised by activated charcoal (3 g.) before the addition of diazomethane (2 g.) in ether (100 ml.) (Arndt, *Org. Synth.*, Coll. Vol. II, p. 165). After 2 hr., the excess of diazomethane was destroyed and the solution washed to neutrality with ice-cold sodium hydrogen carbonate solution. Fractional distillation under reduced pressure gave pure *methyl 5 : 8-dibromo-octanoate* (5·1 g., 76·7%), b. p. 138—140°/1·0 mm., n_D^{21} 1·5083 (Found: C, 34·0; H, 4·96; Br, 50·9. $C_9H_{16}O_2Br_2$ requires C, 34·2; H, 5·1; Br, 50·6%).

(±)-5 : 8-*Thioctic Acid.*—Methyl 5 : 8-dibromo-octanoate (4 g.), thiourea (2 g.), and absolute methyl alcohol (50 ml.) were reflux for 8 hr. before removal of the alcohol under reduced pressure. The gummy residue was dissolved in water (25 ml.), and the solution extracted with ether to remove unchanged thiourea (0·2 g.). Removal of the water under a high vacuum gave the methyl octanoate-5 : 8-dithiuronium dibromide (5·5 g.) as a gum which resisted crystallisation. Addition of sodium picrate (2·5 g.) in water (5 ml.) to the dibromide in water (10 ml.) gave the sparingly soluble *dipicrate*, which crystallised from alcohol as lemon-coloured needles (7·5 g., 78·3%), m. p. 189—192°. This m. p. remained constant throughout a fractional crystallisation (Found: C, 36·05; H, 3·5; N, 17·9. $C_{28}H_{28}O_{16}N_{10}S_2$ requires C, 36·1; H, 3·7; N, 18·3%).

The purified dipicrate (7·5 g.) was added to 2N-hydrochloric acid (50 ml.) and the solution successively extracted with ether or chloroform until the liberated picric acid had been extracted. The final traces were removed from the aqueous phase by treatment with activated charcoal.

The following operations were carried out under an inert atmosphere. To the solution of the dichloride was added 30% sodium hydroxide solution (25 ml.) and the whole refluxed for 2 hr. The cooled solution was extracted once with chloroform, acidified with dilute sulphuric acid, and then extracted with ether (4 × 100 ml.). The combined ethereal extracts were washed once with water and dried before evaporation to dryness under reduced pressure. The residue was dissolved in 5% sodium hydrogen carbonate solution (200 ml.) and treated with 0·1N-alcoholic iodine until the colour of iodine persisted for 30 sec. The solution was then acidified to pH 1 with concentrated hydrochloric acid, and the product extracted with ether (4 × 100 ml.). Evaporation of the ether gave crude (±)-5 : 8-thioctic acid (1·2 g.) as a semi-crystalline magma. Crystallisation from light petroleum (b. p. 40—60°) gave pure (±)-5 : 8-thioctic acid (0·6 g.) as colourless needles, m. p. 57—57·5° (uncorr.). This m. p. could not be further raised by fractional crystallisation from light petroleum and benzene–light petroleum mixtures (Bullock *et al.*, *loc. cit.*, give m. p. 58°) (Found: C, 46·4; H, 6·7; S, 30·9. Calc. for $C_8H_{14}O_2S_2$: C, 46·6; H, 6·8; S, 31%). pK_a' was 6·22 (in 50% ethanol). The infrared spectrum, determined as a mull in Nujol, showed maxima at 2680, 1705, 1419, 1303, 1287, and 935 cm.$^{-1}$.

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*Infrared Spectra and Polar Effects. Part II.**

By L. J. Bellamy.

[Reprint Order No. 6529.]

A number of instances are given in which infrared-frequency shifts of mass-insenstive vibrations can be quantitatively correlated with inductive and mesomeric effects, and it is suggested that in selected cases infrared measurements may provide a reliable measure of these effects and of certain physical properties associated with them.

A number of workers have recently found empirically that group frequency shifts in the infrared region can be correlated with reactivities and other important physical properties. For example, correlations have been found between infrared-frequency shifts and the Hammett σ values of substituted benzenes (Flett, *Trans. Faraday Soc.*, 1948, **44**, 767; Davison, *J.*, 1951, 2456; Fuson, Josien, and Shelton, *J. Amer. Chem. Soc.*, 1954, **76**, 2526; Bellamy, *J.*, 1955, 2818; Scrocco and Liberti, *Ricerca sci.*, 1954, **24**, 1687; Ingraham, Corse, Bailey, and Stitt, *J. Amer. Chem. Soc.*, 1952, **74**, 2297). In addition, Goulden (*Spectrochim. Acta*, 1954, **6**, 129) has found a direct relation between the pK_a values of acids and their OH stretching frequencies, and Bell, Heisler, Tannebaum, and Goldenson (*J. Amer. Chem. Soc.*, 1954, **76**, 5185) have shown that the frequency of the phosphoryl absorption band is a direct function of the sum of the Pauling electronegativities of the substituents. It is the purpose of this paper to suggest a unifying basis for some of these observations, supported by some additional findings.

In considering the influence of polar effects on infrared frequencies we have confined ourselves to those group frequencies which are largely independent of mass or combination effects. The majority of such frequencies arise from vibrations of a single or double bond, –X–Y, in which Y is attached only to X, and any alteration in the frequency will be due primarily to a change in the electron density at X. This is determined by the inductive and mesomeric effects of the substituents on X, so that the extent of the observed frequency shifts will be a direct measure of one or both of these effects as appropriate. Similar reasoning has been applied by Richards and Thompson (*J.*, 1947, 1248) to explain the qualitative shifts observed in amide-carbonyl frequencies, but the quantitative aspects do not appear to have been explored previously. Mesomeric effects arise only in unsaturated molecules and are subject to the steric restriction that the groups producing the effect must lie in the plane of the double bond. It should therefore be possible to isolate the inductive effect by studies on saturated molecules and on unsaturated ones which are not planar.

Inductive Effects.—In saturated compounds, only the motions of hydrogen atoms are largely independent of mass effects and it is therefore encouraging to find that the H–Halogen stretching frequencies as given by Herzberg ("The Infra-Red Spectra of Diatomic Molecules," Van Nostrand, New York, 1950) are a linear function of the halogen electronegativities. Comparisons with other hydrides are complicated by the occurrence of symmetric and asymmetric vibrations but a very close connection between their frequencies and the electronegativity of the central atom is apparent from the work of Gordy (*J. Chem. Phys.*, 1946, **14**, 305) and of Heath, Linnett, and Wheatley (*Trans. Faraday Soc.*, 1950, **46**, 137).

A more straightforward case is that of the OH stretching frequencies of carboxylic acids. The pK_a values of saturated acids are a recognised quantitative measure of the inductive effect of the carboxyl substituent and Goulden's findings (*loc. cit.*) are therefore in accordance with expectation. In the aromatic series the pK_a values are a measure of both inductive and mesomeric effects so that linearity is again to be expected, but the slope of the line obtained should be different from that given by the aliphatic acids. This is of course the case.

The linear phosphoryl relation due to Bell *et al.* (*loc. cit.*) is also readily predicted on this basis, as the symmetry of the phosphate group is such as to cause the substituent groups to

* Part I, *J.*, 1955, 2818.

lie out of the plane of the P=O vibration. Mesomeric effects are therefore eliminated and the only factor influencing the P=O frequency is the inductive effect which is measured by the sum of the electronegativities of the substituents. The "group electronegativities" derived in this way have little physical meaning except as a measure of the inductive effects of the substituents, and it is reassuring that they follow approximately the scale of pK_a values for acids with similar substituents. In the case of the carbonyl absorption for which Kagarise (*J. Amer. Chem. Soc.*, 1955, **77**, 1377) has reported a similar relation the derived "group electronegativities" are widely different and do not appear to be directly related to the inductive effects. This is presumably because of the planar structure of the carbonyl group.

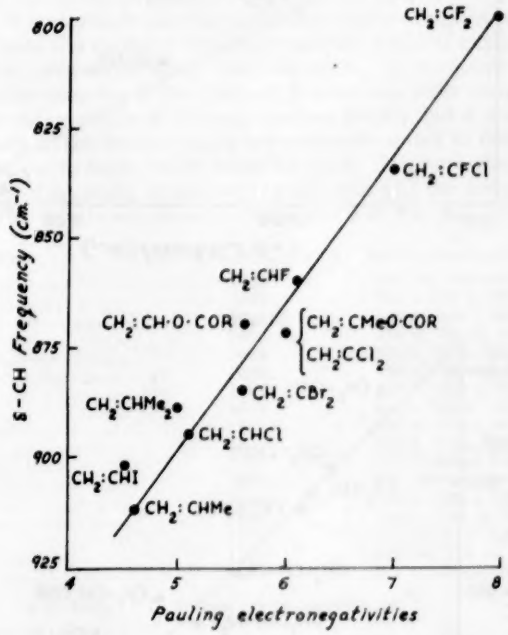
It is to be expected that other non-planar doubly-bonded groups such as >SO, will show a similar linear frequency-dependence upon the electronegativities of their substituents and, although insufficient results are yet available to confirm this, it is interesting that, unlike the carbonyl vibration, the characteristic frequencies of the SO group are very little affected by conjugation whereas they are sensitive to changes in electronegativity. Thus *cyclo*hexyl methyl sulphoxide, methyl phenyl sulphoxide, and diallyl sulphoxide all absorb near 1050 cm.$^{-1}$ (Barnard, Fabian, and Koch, *J.*, 1949, 2442) but thionyl chloride absorbs at 1282 cm.$^{-1}$ (Schrieber, *Analyt. Chem.*, 1949, **21**, 1168).

This hypothesis can also be checked experimentally for the out-of-plane CH_2 deformations of some vinyl and *iso*propenyl compounds $CH_2{:}CRR'$. This vibration occurs near 890 cm.$^{-1}$ in the hydrocarbons and is virtually insensitive to mass effects. Owing to the planar structure it will be subject to both inductive and mesomeric effects and Torkington (*Proc. Roy. Soc.*, 1951, *A*, **206**, 17) and Sheppard and Sutherland (*ibid.*, 1949, *A*, **196**, 195) have discussed the resultant effect upon the frequency in qualitative terms. However, there are instances in which only the inductive effect plays a significant part. Thus, it is known that in the substituted ethylenes $CH_2{:}CHCl$ and $CH_2{:}CFCl$ the mesomeric effects give rise to only about 4—5% double-bond character (Good, *Phys. Rev.*, 1946, **70**, 213), so that in vinyl and vinylidene halides this frequency should be a direct function of the sum of the electronegativities of the RR′ substituents. That this is realised in practise is shown in Fig. 1, in which these electronegativities are plotted directly against the observed frequencies as given by Torkington and Thompson (*Trans. Faraday Soc.*, 1945, **41**, 236; *Proc. Roy. Soc.*, 1945, *A*, **184**, 3, 211). The frequencies of hydrocarbons also fall on this line and are included in Fig. 1 but, in accordance with expectation, none of the oxygenated compounds studied by Davison and Bates (*J.*, 1953, 2607) does so, with two important exceptions. These exceptions are the vinyl and vinylidene esters $CH_2{:}CHR{\cdot}O{\cdot}COR$, etc. These are included in the plot using Davison and Bates's data and their agreement is particularly satisfying, as in these structures there is an internal cancellation of mesomeric effects so that they are the only oxygenated derivatives which could be expected to follow the linear electronegativity function. The existence of this internal cancellation is clearly shown in the absence of resonance energy in vinyl acetate (Ingold, "Structure and Mechanism in Organic Chemistry," Bell, London, 1954, p. 117) and can also be demonstrated directly from infrared data. The carbonyl frequencies of vinyl esters are abnormally high (vinyl acetate absorbs at 1776 cm.$^{-1}$), indicating a shortening of the C=O bond. Clearly therefore any contribution from a mesomeric form $CH_2{:}CR{\cdot}{}^{+}O{:}CR{\cdot}O^{-}$, in which the bond would be lengthened, must be extremely small.

Combined Inductive and Mesomeric Effects.—In an unsaturated compound in which the substituents at the double bond lie in the same plane, it is to be expected that any mass-insensitive vibrations involving the double bond will be subject to the resultant of both inductive and mesomeric effects, and the frequency shifts following changes in the substituents should be a quantitative measure of this resultant effect. Unfortunately, in seeking experimental evidence it is difficult to find parameters for this resultant effect which can be accurately measured. Resonance energies, for example, determine only the mesomeric effect, so that they are unlikely to be directly related to infrared frequencies, although there does appear to be a relation with infrared intensities (Barrow, *J. Chem. Phys.*, 1953, **21**, 2008). However, two parameters which appear to offer some possibilities in this respect are atomic refractivity exaltations and, in selected cases, reactivity.

Atomic-refractivity exaltations. The property of the exaltation of the molecular refraction of visible light over the value from the sum of the individual atomic refraction constants is a common property of unsaturated systems and is a measure of the tendency for mesomeric displacement. However, when the atomic exaltation is determined by the usual method of measuring the differences between related aryl and alkyl compounds it contains also an element of electronegativity (Ingold, *op. cit.*, p. 127). This arises from the fact that electronegative groups have a greater influence on the more polarisable aryl group than on the alkyl group. The exaltations of atomic refraction constants measured in this way therefore provide at least a rough guide to the resultant of the *I* and the *M* effect. Ingold (*op. cit.*, p. 129) gives a table of positive and negative exaltations of refraction of a

FIG. 1.



series of carbonyl compounds compared with the ester forms. These values have been plotted in Fig. 2 against typical carbonyl frequencies of the various forms and it will be seen that the agreement is surprisingly good. The frequencies employed were as follows: R·COCl 1800, R·CO_2R 1740, R·CO_2H 1708, R·CO·NR_2 1645, and R·CO_2^- 1560 cm.$^{-1}$. These were chosen as being typical values for the condensed state in which the refractivities were measured and the 1560 cm.$^{-1}$ band of ionised acids was chosen in preference to the mean of the asymmetric and the symmetric vibrations on the grounds that the corresponding C⁻⁻O bond in aluminium halide complexes of ketones, in which only a single oxygen is involved, absorbs near this point (Susz and Cooke, *Helv. Chim. Acta*, 1954, **37**, 1273; Cooke, Susz, and Hershmann, *ibid.*, p. 1280).

A similar plot (Fig. 3) shows atomic refraction exaltations plotted against the CH_2 out-of-plane deformation frequencies of vinyl compounds. In the absence of more precise data we have had to employ exaltations based on comparisons between aromatic and alkyl compounds (Ingold, *op. cit.*, pp. 127, 128, 136) rather than between alkenyl and alkyl compounds, but it will be seen, after allowance for this, that the agreement is reasonable

and that it is now possible to take account of Davison and Bates's data (*loc. cit.*) for those oxygenated compounds which do not follow the electronegativity relation of Fig. 1.

Reactivities. The resultant of the *I* and the *M* effect is also measured directly by reactivities, in selected cases in which electromeric effects are small. For aromatic compounds the series of papers referred to above relating Hammett's σ values to infrared

FIG. 2.

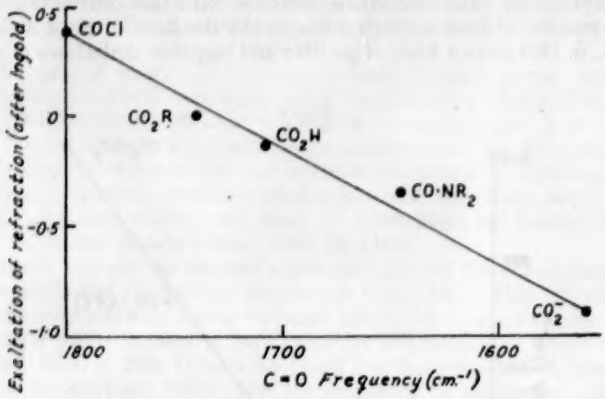
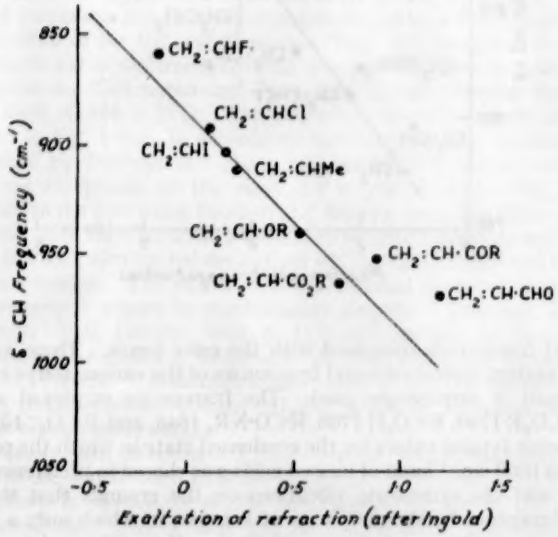


FIG. 3.



frequencies has already established that a relation exists between frequencies and reactivites within this limited series. It is more difficult to establish a similar relation for aliphatic substituents as no comparable kinetic data are available. Taft (*J. Amer. Chem. Soc.*, 1953, **75**, 4231) derived a number of constants for alkyl groups which related to reactions in which only inductive effects play a part and it is reassuring to find that we obtain a linear function on plotting these against the OH stretching frequencies of the corresponding alkyl acids

given by Goulden. However no suitable data covering both *I* and *M* effects are available for this series.

For benzoyl compounds the carbonyl frequencies of any series of *m*- or *p*-substituted compounds $X{\cdot}C_6H_4{\cdot}COR$ are a linear function of the Hammett σ values (Josien *et al.*, *loc. cit.*), and a change in the group R gives rise to a similar function which is parallel with the first. This implies that the change in the group R has brought about a constant change which is related to the change in the *I* and the *M* effects which it introduces. As, however, this cannot be demonstrated quantitatively in the absence of suitable kinetic data for alkyl groups, we have explored the possibility of obtaining some further data by a study of the internal relation between the carbonyl and the ring frequencies. If in a series of unsubstituted benzoyl compounds Ph·COR the carbonyl frequency is a function of the *I* and the *M* effect of the R group (the influence of the ring remaining constant), the demands for electrons which the carbonyl group makes upon the ring should vary proportionately in the same way. It is therefore possible that in any single compound of this type a direct relation exists between the carbonyl frequency and the δ-CH vibrations which for monosubstituted aromatic compounds occur near 750 cm.$^{-1}$. In monosubstituted compounds this vibration is rather complex in its origin, as it is derived from vibrations of a group of hydrogen atoms on carbon atoms of differing electron density, but it was hoped that within a constant series such as the benzoyl series any interactions due to this might be constant and that differences due to mass effects would be small. We have therefore measured the carbonyl frequencies of a variety of carbonyl compounds and the frequencies in the range 850—650 cm.$^{-1}$. The results are shown in the Table and Fig. 4. The results for benzo-

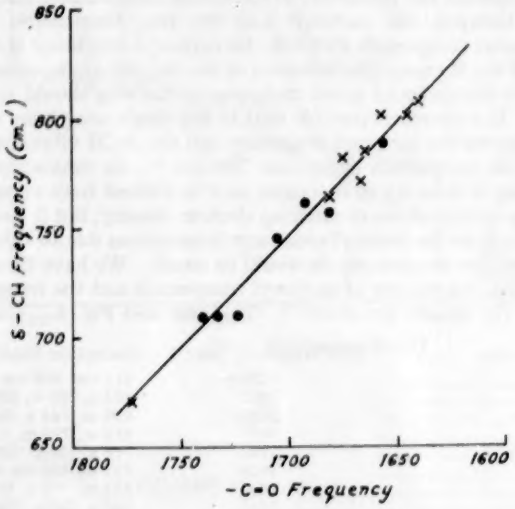
Compound	C=O frequency (cm.$^{-1}$)	Absorption bands at 850—850 cm.$^{-1}$
$Ph{\cdot}CO_2H$	1730 [a]	811 vw, 806 vw, ***714*** vs, 683 s
Ph·COMe	1692	***761*** s, 730 w, 690 *s*
Ph·CHO	1705	826 m, ***745*** s, 687 s
$Ph{\cdot}CO{\cdot}NH_2$	1675	810 w, 790 m, ***771*** ms, 704 s, 684 s
$Ph{\cdot}CO{\cdot}[CH_2]_2{\cdot}COPh$	1681	***772*** s, 735 s, 692 s
Ph·CO·CH:N·OH	1656	***788*** m, 698 vs, 682 w
Ph·CO·CH:CHPh	1664	***784*** m, 750 s, 688 s
$Ph{\cdot}CO{\cdot}NMe_2$	1645	***800*** s, 738 s, 724 s, 698 m
$Ph{\cdot}CO{\cdot}NH{\cdot}CH_2{\cdot}CO_2H$	1640 [b]	***807*** m, 722 s, 707 m, 704 m
Ph·CO·CHPh·OH	1681	***756*** s, 702 s, 694 m, 681 m, 673
Ph·COCl	1773 [c]	772 m, 684 s, ***671*** vs
Ph·CO·NHMe	1657	804, ***801*** m, 719 s, 708 s, 694 s
$COPh_2$	1664	***756*** m, 700 s, 694 vw, 681 vw
Ph·CO·COPh	1675	***794*** m, 724 m, 717 s, 690 m, 680 m
$Ph{\cdot}CO_2Me$	1724	820 vw, ***710*** vs, 687 w, 675 w
$Ph{\cdot}CO_2Et$	1733	809 vw, ***710*** vs, 685 w, 674 w
Ph·CO·CPh:N·OH	1667	***771*** w, 730 m, 692 s

[a] In CCl_4. [b] In dioxan. [c] In *cyclo*hexane.

phenone and for benzil, in which obvious interaction effects are to be expected, have been omitted from the plot but they are included in the Table and it will be seen that even these show an approximate agreement. The agreement for the remainder is very satisfactory, but these results cannot be regarded as conclusive at present owing to the difficulty in accurately identifying the δ-CH vibration in all cases. Within the range 850—650 cm.$^{-1}$ all the compounds studied show at least one additional band (near 690 cm.$^{-1}$) and sometimes two. The first of these is invariant in position and can be discounted, but the appearance of a second band in many cases makes the identification of the δ-CH mode difficult. In compounds such as benzaldehyde the δ-CH band is readily recognisable by its intensity, but it appears to show a progressive weakening as its frequency rises, so that in ω-hydroxyiminoacetophenone it is of only moderate intensity. In the last case identification is simplified by the absence of other bands and we are therefore encouraged in our identification of bands of similar intensity in other compounds. However, the acceptance of our identifications implies a wider range of both frequency and intensity than is usual for the δ-CH vibration and, to avoid confusion, those points in Fig. 4 for which identification can be made with reasonable certainty have been indicated by black dots and the remainder by crosses. Nevertheless, with so few bands in this region it would be a surprising coincidence

if in each case a random band happened to occur at the right point to correlate with the carbonyl frequency in the way which we have found. Margoshes and Fassel (*Spectrochim. Acta*, 1955, **7**, 14) also have pointed out that the carbonyl group, along with the nitro-group, can change very considerably the δ-CH frequency, although we do not agree with their assignments in all cases. The frequencies of all bands in the 850—650 cm.$^{-1}$ region are included in the Table, and the particular band which has been employed in the plot is italicised in each case.

FIG. 4.



Conclusions.—There appear to be at least strong grounds for the supposition that the study of infrared shifts of mass-insensitive vibrations can afford a resonably precise relative measurement of the I and the $(I + M)$ effects of substituent groups. This, coupled with the possibility of the independent measurement of M effects through intensity studies, has important implications in the field of kinetics. In addition, frequency shifts of this type may be expected to be correlated directly with other physical properties which depend upon these effects. The fact that a number of empirical correlations of this type have already been observed, in addition to these already mentioned, lends further support to this idea. Typical physical properties correlated in this way in limited cases include half-wave potentials with carbonyl frequencies (Josien *et al.*, *loc. cit.*), chelate stabilities with carbonyl frequencies (Bellamy and Branch, *J.*, 1954, 4491), bond strengths (Bellamy and Beecher, *ibid.*, p. 4487), and reactivities of alcohols (Taft, *loc. cit.*). In addition, the observed linearity of carbonyl frequencies with Hammett's σ values implies also a direct relation with redox potentials which are themselves a linear function of σ.

Experimental.—The spectra were measured in a Perkin-Elmer 21 double beam spectrometer fitted with a rock-salt prism. Samples were examined in very dilute solution in chloroform (or other nonpolar solvents where indicated), in 0·05 mm. cells. The low-frequency region was studied either in the condensed phase or in solution in *cyclo*hexane or dioxan.

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EXPLOSIVES RESEARCH AND DEVELOPMENT ESTABLISHMENT,
MINISTRY OF SUPPLY, WALTHAM ABBEY, ESSEX.

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Synthesis of Aleprestic Acid.

By B. WLADISLAW.

[Reprint Order No. 6598.]

Chain extension of *cyclo*pent-2-enylacetic acid by electrolysis with methyl hydrogen glutarate gives (±)-aleprestic acid. Evidence is presented for the position of the double bond in *cyclo*pent-2-enylacetic and aleprestic acid.

THE synthesis of saturated and unsaturated fatty acids by anodic cross-coupling of monocarboxylic acids with half esters of dicarboxylic acids (Linstead, Weedon, and Wladislaw, *J.*, 1955, **1097**) led us to apply a similar procedure to the synthesis of some acids of chaulmoogra oil, containing the *cyclo*pent-2-enyl group. Interest in these compounds has grown recently, especially concerning the preparation of lower homologues not available from natural sources.

Aleprestic acid (δ-*cyclo*pent-2-enylvaleric acid), which occurs only in a very small amount (<0·5%) in *Hydnocarpus wightiana* oil, was first chosen because of its structural relation to thioctic acid.* It has been obtained by Cole and Cardoso (*J. Amer. Chem. Soc.*, 1939, **61**, 2349) by repeated fractional distillation of the ethyl esters. Comparison of its measured specific rotation with the estimated value seems to indicate that it was only about 70·5% pure; its synthesis, however, has not yet been reported.

Electrolysis in methanol of (±)-*cyclo*pent-2-enylacetic acid in the presence of an excess of methyl hydrogen glutarate, followed by alkaline hydrolysis of the ester formed, gave (±)-aleprestic acid in 27·5% yield. Of the two expected products of symmetrical coupling, suberic acid, but not 1 : 2-di*cyclo*pentenylethane, was identified.

Electrolysis of *cyclo*pent-2-enylacetic acid alone in methanol could not be performed owing to coating of the anode with insoluble polymers and consequent fall in the current. The same occurred when in place of the methyl half ester the benzyl half ester was employed.

Weedon (*Quart. Rev.*, 1952, **6**, 387) mentioned difficulties in the electrolysis of ethylenic acids due to coating of the anode with insoluble polymers, but to our knowledge complete inhibition has not been reported before. On the other hand, there are no references to the use of benzyl half esters in cross-coupling reactions with unsaturated acids. The complete inhibition observed cannot be explained at present.

No direct proof has yet been given that the double bond in the *cyclo*pentenylacetic acid is in the 2-position. Noller and Adams (*J. Amer. Chem. Soc.*, 1926, **48**, 2444), who described the preparation of *cyclo*pentenyl chloride and *cyclo*pentenylacetic acid, assumed the 2-position of the double bond on the basis of the chemical reactivities. We now provide a more rigorous proof. Of the three possible isomers only that with the double bond in the 2-position can exist in optically active forms. By treatment of our (±)-*cyclo*pentenylacetic acid with quinine we obtained the (+)-acid.

Although the anodic chain-extension method was shown in the erucic–brassidic series to give products without migration of the double bond (Bounds, Linstead, and Weedon, *J.*, 1953, 2393), it was necessary to prove that also for the *cyclo*pentenyl series. Use of (+)-*cyclo*pent-2-enylacetic acid in the anodic synthesis furnished (+)-aleprestic acid in 28% yield, proving that the 2-position of the double bond is maintained through the three-carbon homologation of its side chain. It confirms also the observation (Ställberg-Stenhagen, *Arkiv Kemi*, 1950, **2**, 95; Linstead, Lunt, and Weedon, *J.*, 1950, 3333; 1951, 1130) that optical activity involving an asymmetric carbon atom which is not directly attached to the carboxylic group eliminated in the reaction is preserved during the electrolysis.

The specific optical rotation of our aleprestic acid was $[\alpha]_D^{20}$ +74°, which is higher than that (+60·9°) of the aleprestic acid isolated from the *H. wightiana* oil (*loc. cit.*), but lower than that estimated (+100·5°) from the curve for the other homologues of this series. Our (+)-*cyclo*pent-2-enylacetic acid, with $[\alpha]_D^{20}$ +57°, may have been only partially resolved but we have no method of checking this. The anodic synthesis of the homologues of aleprestic acid and thioctic acid are being studied.

* The biological aspect of this relation is being studied.

Experimental

(±)-cyclo*Pentenylacetic Acid* (cf. Noller and Adams, *J. Amer. Chem. Soc.*, 1926, **48**, 2444).—Freshly distilled *cyclo*pentadiene was converted into *cyclo*pent-2-enyl chloride by reaction with dry hydrogen chloride with cooling by solid carbon dioxide. The chloride, immediately after distillation (b. p. 27—29°/20 mm.) (yield 84·5%), was condensed with ethyl sodiomalonate with ice-cooling. The product, worked up in the usual way, gave diethyl *cyclo*pent-2-enylmalonate (84%), b. p. 120°/5 mm., n_D^{21} 1·4535. Hydrolysis by 20 hours' boiling with aqueous sodium hydroxide (15%) gave *cyclo*pent-2-enylmalonic acid (96·5%), m. p. 149—150° (from benzene). This acid at 190° gave *cyclo*pent-2-enylacetic acid (97%), b. p. 94·5°/3 mm., n_D^{20} 1·4684 (Found: C, 66·6; H, 7·9. Calc. for $C_7H_{10}O_2$: C, 66·6; H, 7·9%).

(+)-cyclo*Pent-2-enylacetic Acid.*—The (±)-acid (20 g., 0·16 mole) was dissolved in a solution of sodium hydroxide (6·3 g., 0·16 mole) in water (250 c.c.) and added gradually to a warm solution of quinine hydrochloride (31 g., 0·08 mole) in water (2·5 l.). The solution was boiled for 5 min., then cooled. The quinine salt of the (+)-acid separated and after recrystallization once from water (*ca.* 3·5 l.) was obtained as colourless crystals (14·4 g.), m. p. 113—115°, $[\alpha]_D^{18}$ −114·6° (*l*, 1; *c*, 2 in EtOH). The rotation remained constant on further recrystallization.

The quinine salt (14·4 g.) was dissolved in warm water (*ca.* 1·6 l.) and, after the solution had been cooled rapidly, the equivalent amount of 2N-hydrochloric acid was added. The regenerated acid was extracted with ether, and the ethereal solution was washed with a small volume of water, dried, and evaporated. Distillation of the residue gave (+)-*cyclo*pent-2-enylacetic acid (3·4 g., 34%), b. p. 110°/6 mm., $n_D^{19\cdot5}$ 1·4684 (Found: C, 66·5; H, 7·7%), $[\alpha]_D^{20}$ +57° (*l*, 1; *c*, 2 in $CHCl_3$).

The mother-liquors were evaporated in a vacuum to 1 l. and more quinine salt was separated; this had m. p. 107—112°, which was not improved by further crystallizations. Further concentration gave no more quinine salt.

(−)-cyclo*Pentenylacetic Acid.*—After separation of the quinine salt, a small portion of the mother-liquor was added to a warm solution of quinidine sulphate, but only an oil separated. Then the whole of the mother-liquor was treated with hydrochloric acid and the crude (−)-*cyclo*pent-2-enylacetic acid extracted with ether. The ethereal solution was washed with a small volume of water, dried, and evaporated. Distillation of the residue gave (−)-*cyclo*pent-2-enylacetic acid (6·4 g., 64%), b. p. 90·5°/2·5 mm., n_D^{23} 1·4675, $[\alpha]_D^{20}$ −33·1° (*l*, 1; *c*, 2·4 in $CHCl_3$).

(±)-*Aleprestic Acid.*—A mixture of (±)-*cyclo*pent-2-enylacetic acid (6 g., 0·047 mole) and methyl hydrogen glutarate (b. p. 124°/4 mm., $n_D^{23\cdot5}$ 1·4372; prepared from the anhydride and methanol in 98% yield) (21·1 g., 0·144 mole) in methanol (80 c.c.) was electrolysed (current 0·6 amp.; cf. Linstead, Weedon, and Wladislaw, *loc. cit.*). The cell contents were filtered from a colourless polymer, acidified with glacial acetic acid, and evaporated. The residue was extracted with ether (500 c.c.), and the solution was washed with 2N-sodium hydroxide, then dried (Na_2SO_4) and evaporated. By the distillation of the residue, 0·5 g. of a fraction, b. p. 47—48°/15 mm., was removed. The remaining liquid (12 g.) was hydrolysed by stirring it under reflux for 4 hr. with a 2N-solution of sodium hydroxide in methanol–water (4 : 1) under nitrogen. After addition of water, the methanol was distilled off in nitrogen and the aqueous solution was extracted with ether and then with benzene. Evaporation of both extracts gave no residue. The ether- and benzene-insoluble material was treated with excess of 30% hydrochloric acid and the resulting acids were extracted with ether. The residue left on evaporation of ether was extracted with chloroform. Separation of the insoluble material gave suberic acid (5 g., 39·6%), m. p. 139—140°. The chloroform solution was evaporated and the distillation of the residue gave (±)-aleprestic acid (2·2 g., 27·5%), b. p. 126—127°/3 mm., n_D^{20} 1·4711 (Found: C, 71·3; H, 9·5. Calc. for $C_{10}H_{16}O_2$: C, 71·4; H, 9·6%).

(+)-*Aleprestic Acid.*—(+)-*cyclo*Pent-2-enylacetic acid (2·55 g., 0·020 mole) and methyl hydrogen glutarate (11 g., 0·075 mole) in methanol (40 c.c.) were electrolysed (current 0·6 amp.) as in the preceding experiment. (+)-Aleprestic acid (0·95 g., 28%), b. p. 139—140°/5 mm., $n_D^{20\cdot5}$ 1·4690, $[\alpha]_D^{20}$ +74° (*l*, 1; *c*, 1·3 in $CHCl_3$) (Found: C, 71·65; H, 9·6%), and suberic acid (2·4 g., 36·9%), m. p. 139—140°, were obtained.

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Synthetic Œstrogens. Part III. The Free-radical Dimerisation of Arylacetic Acids and Arylacetones.*

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[Reprint Order No. 6617.]

The synthesis of *meso*- and racemic αα'-di-*p*-hydroxyphenylsuccinic acid (I) by free-radical dimerisation of *p*-methoxyphenylacetic acid and its ethyl ester and subsequent hydrolysis is described. The dimerisation of some related acids and of certain arylacetones has also been studied.

The succinic acid derivative (I), prepared in one (presumably racemic) stereomodification only, has been reported to be biologically highly active (Hoch, *Compt. rend.*, 1950, **231**, 625). In a study of the stereochemical effect on biological activity, both *meso*- and racemic forms of this acid have now been prepared, by a free-radical dimerisation. Attempts to synthesise the higher homologues (II), (III), and (IV) by the same method were unsuccessful.

$$(p\text{-HO}\cdot C_6H_4\cdot \underset{\text{R}}{\overset{|}{C}}\text{H}\cdot CO_2H)_2$$

(I): R = H (III): R = Et
(II): R = Me (IV): R = Pr^n

" Dimerisation " (see footnote, Part II) of ethyl *p*-methoxyphenylacetate with di-*tert.*-butyl peroxide at 140°, as previously described, gave diethyl *meso*-αα'-di-*p*-methoxyphenylsuccinate. (In this work the higher-melting and less-soluble isomer is assigned the *meso*-configuration.) Treatment of this diester with alcoholic potassium hydroxide at 180° in a sealed tube resulted in hydrolysis, as well as isomerisation, to the racemic αα'-di-*p*-methoxyphenylsuccinic acid, m. p. 214—215° (acid A). Hydrolysis with the same reagent at 80°, however, was attended by partial isomerisation only, giving a mixture of the *meso*-acid, m. p. 272—273°, and an acid of m. p. 202—203°, resolidifying, and remelting at 238—239° (acid B); prolonged boiling with the reagent gave the acid B only. Since acid B has ultraviolet absorption ($\lambda_{max.}$ 277 mμ; ε 28,000) identical with that of the racemic acid A, it is believed to be a polymorphic form of the latter, rather than a mixture with the *meso*-form. Demethylation of acid B with hydrobromic acid furnished the required racemic hydroxy-acid (I).

Dimerisation of *p*-methoxyphenylacetic acid led to the *meso*-succinic acid whose stereochemical relation with the ester series was established by its complete isomerisation to the racemic acid A by potassium hydroxide in ethanol at 180° or in boiling diethylene glycol. (No demethylation took place under these conditions.) Demethylation of the *meso*-ester, by a modified method, furnished the *meso*-succinic acid (I).

The predominant formation of one stereomodification (*meso* in both cases) during free-radical dimerisation of both acid and ester was unexpected, but not without precedent. *E.g.*, Kharasch, McBay, and Urry (*J. Org. Chem.*, 1945, **10**, 394) in their dimerisation of dimethyl succinate with acetyl peroxide obtained a product containing ⩽98% of the *meso*-isomer. Isomerisation of diastereoisomers of related acids under the action of alkalis is well known (see, *e.g.*, Wren and Still, *J.*, 1915, 107).

From the melting points, it appears that the diester, m. p. 145°, obtained by Hoch (*loc. cit.*) is the *meso*-form but that his methoxy- and hydroxy-acids, m. p. 220° and 230° respectively, consisted mainly, but not entirely, of the racemic diastereoisomers.

p-Methoxyphenylacetic acid was best prepared by a modification (see Experimental section) of the method of Levine, Eble, and Fischbach (*J. Amer. Chem. Soc.*, 1948, **70**, 1930). Other methods (Cain, Simonsen, and Smith, *J.*, 1913, 1035; Kondo and Oshima, *J. Pharm. Soc. Japan*, 1931, **51**, 979; Kindler, Metzendorf, and Dschi-yin-Kwok, *Ber.*, 1943, **76**, 308) involve difficultly accessible starting materials or give low yields.

meso-Di-*p*-methoxyphenylsuccinic acid (VI) is insoluble in the usual organic solvents,

* Part II, *J.*, 1954, 2570.

and demethylation by the usual procedures failed, but hydrogen bromide in glacial acetic acid gave the *meso*-hydroxy-acid (I) in satisfactory yield.

In attempted synthesis of the homologues (II), (III), and (IV), α-phenyl-propionic and -butyric acid and their ethyl esters, and ethyl α-phenylvalerate, were treated with di-*tert.*-butyl peroxide in the usual way, but the expected dimers were not obtained. (The *p*-hydroxy-groups were to be introduced subsequently *via* the dinitro-compounds, as in Part II.) Since ethyl phenylacetate reacts normally under similar conditions (Huang and Morsingh, unpublished results), presumably the α-alkyl substituents prevent the reaction, rendering disproportionation possible. A difference also exists between these acids and esters and the corresponding alkylated benzyl cyanides reported in Part II, but a parallel is found in the contrasting properties of the free 2-cyano-2-propyl and 2-ethoxycarbonyl-2-propyl radicals, the latter showing much greater tendency to disproportionation (Bickel and Waters, *Rec. Trav. chim.*, 1950, **69**, 312, 1490). Among aliphatic acids, *iso*butyric acid dimerises normally, though not in high yields, when treated with diacetyl peroxide at 80° (Kharasch and Gladstone, *J. Amer. Chem. Soc.*, 1943, **65**, 15) and *cyclo*hexanecarboxylic acid behaves similarly with di-*tert.*-butyl peroxide at 140°.

Another approach to the acids (II), (III), and (IV) was suggested by the work of Kharasch, McBay, and Urry (*J. Amer. Chem. Soc.*, 1948, **70**, 1269) who obtained diphenylsuccinic acid in unspecified yields by hypobromite oxidation of the dimer obtained from phenylacetone and diacetyl peroxide. 3-Phenylbutan-2-one with di-*tert.*-butyl peroxide gave a fair yield of mixed isomeric "dimers," which could not be separated; 3-*p*-methoxyphenylbutan-2-one also gave low yields of a mixture which on oxidation with sodium hypochlorite afforded small quantities of chlorine-containing acids. On the other hand, *p*-methoxyphenylacetone under the same conditions gave good yields of *meso*- and racemic 3 : 4-di-*p*-methoxyphenylhexane-2 : 5-dione. Oxidation of these with alkaline hypochlorite, however, also proved unsatisfactory: both isomers were unstable to alkali, being converted readily by 1% potassium hydroxide in aqueous alcohol into the same diaryl*cyclo*pentenone.

Both *meso*- and racemic αα′-di-*p*-hydroxyphenylacetic acid (I) were inactive in doses of 5 and 10 mg., respectively, when injected in aqueous solution into ovariectomised rats. This is not surprising in view of the total inactivity of *meso*- and racemic βγ-di-*p*-hydroxyphenyladipic acid (Dodds, Huang, Lawson, and Robinson, *Proc. Roy. Soc.*, 1953, *B*, **140**, 470; Lawson, personal communication).

Experimental

Ethyl p-*Methoxyphenylacetate.*—*p*-Anisaldehyde bisulphite compound (from 150 g. of anisaldehyde; cf. Levine *et al.*, *loc. cit.*) was added with stirring to an ice-cold solution of potassium cyanide (170 g. in *ca.* 250 c.c. of water), covered with ether (400 c.c.), to which had been added potassium hydroxide (4 g.) (essential for a good yield). The ether layer was separated, washed with a solution of sodium metabisulphite and then water, and dried. On removal of the ether and addition of light petroleum (b. p. 50—60°), the cyanohydrin crystallised (m. p. 61—63°; 148 g.). A portion (50 g.) was reduced and hydrolysed by 3 hours' refluxing with stannous chloride (100 g.) in acetic acid (100 c.c.), concentrated hydrochloric acid (100 c.c.), and hydriodic acid (7 c.c.; *d* 1·7). After cooling, the stannic chloride which separated was filtered off, and the filtrate diluted with water, extracted with carbon tetrachloride, and distilled, giving *p*-methoxyphenylacetic acid, b. p. 138—140°/2—3 mm., m. p. 82° (45 g.). This gave, with ethanol and sulphuric acid, the ethyl ester (27 g.), b. p. 100—102°/1 mm., n_D^{23} 1·5780.

Ethyl meso-αα′-*Di*-p-*methoxyphenylsuccinate.*—(*a*) Ethyl *p*-methoxyphenylacetate (18·2 g.) and di-*tert.*-butyl peroxide (10 g.) were heated in a sealed tube at 140—150° for 24 hr. After distillation of the volatile fractions and unchanged ester (12 g.), addition of methanol gave ethyl *meso*-αα′-di-*p*-methoxyphenylsuccinate (2·2 g.), m. p. 143—144° after recrystallisation from methanol (Hoch, *loc. cit.*, reports m. p. 145°).

(*b*) Ethyl *p*-methoxyphenylacetate (27 g.) and di-*tert.*-butyl peroxide (15 g.) were heated under reflux for 48 hr. After removal of unchanged ester (16 g.) and addition of methanol, the same dimeric *meso*-ester separated (m. p. 143—144°; 2·1 g.), and was filtered off. The filtrate was refluxed with 10% aqueous sodium hydroxide (50 c.c.) for 8 hr., cooled, extracted twice with ether, and acidified with 5N-sulphuric acid, and the precipitated acid was taken up in

ether. Removal of ether afforded the racemic *acid B*, which crystallised from ethanol in prisms, m. p. 202—203°, resolidifying, and remelting at 238—239° (2·1 g.) (Found: C, 65·1; H, 5·5. $C_{16}H_{16}O_6$ requires C, 65·4; H, 5·5%).

Hydrolysis and Isomerisation.—(*a*) The above succinic ester (0·50 g.) was heated in 15% alcoholic potassium hydroxide (15 c.c.) in a sealed tube at 180—190° for 6 hr. Water was added, and the product worked up as described above, giving racemic *αα'-di*-p-*methoxyphenylsuccinic acid A*, which crystallised from methanol in prisms, m. p. 214—215° (0·33 g.) (Found: C, 65·5; H, 5·6; OMe, 19·1. $C_{18}H_{18}O_6$ requires C, 65·4; H, 5·5; OMe, 18·8%).

(*b*) The above ester (0·42 g.) was heated with 5% alcoholic sodium hydroxide (20 c.c.) for 1·5 hr. The product gave (i) racemic αα'-di-*p*-methoxyphenylsuccinic acid B, double m. p. 202—203°, 238—239° (0·22 g.) (Found: C, 65·7; H, 5·7%), and (ii) a small quantity of the *meso*-acid (*ca.* 30 mg.).

Demethylation.—The above racemic acid B (0·5 g.) was heated in acetic acid (5 c.c.) and hydrobromic acid (3 c.c.; *d* 1·47) at 80° for 5 hr. Water was added, and the acetic acid removed under a partial vacuum, the resulting solution being then extracted once with chloroform before exhaustive extraction with ether. Removal of ether afforded racemic *αα'-di*-p-*hydroxyphenylsuccinic acid*, m. p. 201—210° (0·18 g.) raised to 225—226° (decomp.) after six recrystallisations from benzene–ethanol (Hoch reports m. p. 230° for his impure acid) (Found: C, 63·0, 63·0; H, 4·9, 5·1. $C_{16}H_{14}O_6$ requires C, 63·5; H, 4·7%). The m. p. gradually dropped to 217—220° after a few weeks. The product was soluble in water. Demethylation with acetic and hydriodic acids was not successful.

meso-*αα'-Di*-p-*methoxyphenylsuccinic Acid.*—*p*-Methoxyphenylacetic acid (28 g.) and di-*tert.*-butyl peroxide (17·5 g.), heated for 48 hr. at 140°, deposited a solid, m. p. *ca.* 267° (5·1 g.), which was filtered off. It was practically insoluble in all the usual organic solvents, but when crystallised from much dioxan, gave the required *meso*-succinic acid, m. p. 272—273° (Found: C, 65·0; H, 5·4%). The filtrate was concentrated, and treated with ethanol to induce crystallisation. This failing, the mixture was esterified with ethanol (100 c.c.) and concentrated sulphuric acid (4 c.c.) to give, on distillation, the *meso*-ester obtained previously, m. p. 142—143° (*ca.* 1·7 g.). Thus no racemic acid was obtained in the above dimerisation.

Isomerisation.—(*a*) The above *meso*-succinic acid (0·50 g.), when heated at 190—200° for 16 hr. with a 15% alcoholic solution of potassium hydroxide (12 c.c.) in a sealed tube, gave the racemic acid, m. p. 207—209° (0·40 g.), raised to 214—215° after recrystallisation from ethanol, alone or mixed with the acid A obtained above.

(*b*) Heating with a solution of the same reactants in ethylene glycol under reflux for 4·5 hr. (210—220°) gave a lower yield (35%) of the racemic acid A. In each case no demethylation occurred.

Demethylation.—The above *meso*-acid (0·65 g.) was dissolved in boiling acetic acid (*ca.* 300 c.c.), cooled to *ca.* 70°, then saturated with dry hydrogen bromide, kept at this temperature for 36 hr., and finally heated at 100° for 5 hr. Water was added, and the solution concentrated under reduced pressure. This being repeated, the resulting aqueous solution was extracted once with chloroform, then four times with ether. The ethereal extracts, after drying, were concentrated, and the solid which separated (0·45 g.) was recrystallised from ethanol–benzene, giving *meso-αα'-di*-p-*hydroxyphenylsuccinic acid*, m. p. 284° (decomp.), becoming slightly yellow at *ca.* 260° (Found: C, 63·5; H, 5·0. $C_{16}H_{14}O_6$ requires C, 63·5; H, 4·7%). It is soluble in cold water.

Dimerisation of cyclo*Hexanecarboxylic Acid.*—This acid (25 g.) and di-*tert.*-butyl peroxide (17 g.), after refluxing for 48 hr., gave on distillation (i) unchanged acid (15 g.), (ii) *dicyclohexyl-1 : 1'-dicarboxylic anhydride*, b. p. 140—143°/0·5 mm. (3·6 g.), m. p. 144—145° (from methanol) (Found: C, 71·5; H, 8·55. $C_{14}H_{20}O_3$ requires C, 71·2; H, 8·5%), and (iii) a residue (3·2 g.), sparingly soluble in ethanol, but soluble in benzene, and decolorising bromine in carbon tetrachloride. The anhydride was insoluble in aqueous sodium carbonate, but dissolved in aqueous sodium hydroxide by which it was hydrolysed to the *acid*, m. p. 255° after recrystallisation from ethanol–benzene (Found: C, 66·1; H, 8·7. $C_{14}H_{22}O_4$ requires C, 66·6; H, 8·5%).

Dimerisation of 3-*Phenylbutan*-2-*one.*—This ketone (33 g.) (Suter and Weston, *J. Amer. Chem. Soc.*, 1942, **64**, 533) and the peroxide (20 g.) were heated at 140° for 48 hr., and the product distilled, giving (i) unchanged ketone (20 g.), (ii) a viscous oil, b. p. 156—159°/2 mm. (6·5 g.), probably a mixture of *meso*- and racemic 3 : 4-dimethyl-3 : 4-diphenylhexane-2 : 5-dione (Found: C, 82·0; H, 7·2. Calc. for $C_{20}H_{22}O_2$: C, 81·6; H, 7·5%). It was soluble in methanol and ethyl acetate, but attempts at recrystallisation failed.

Dimerisation of p-*Methoxyphenylacetone.*—The ketone (55 g.) (Shepard, Noth, Porter, and

Simmans, *ibid.*, 1952, **74**, 4611) and di-*tert.*-butyl peroxide (30 g.), after 48 hr. under reflux, deposited a mixture of *meso*- and racemic **3** : **4**-*di*-p-*methoxyphenylhexane*-**2** : **5**-*dione* which was filtered off. Boiling methanol removed the racemic isomer, which separated from this solvent in light yellow prisms, m. p. 153—154° (6·7 g.) (Found : C, 73·4; H, 6·7. $C_{20}H_{22}O_4$ requires C, 73·6; H, 6·8%). The meso-*isomer*, which was sparingly soluble in methanol, crystallised from dioxan in prisms, m. p. 201—202° (8·4 g.) (Found : C, 73·7; H, 7·0%). The filtrates were concentrated and distilled, giving unchanged starting material (30 g.), and more of the racemic isomer, m. p. 140—150° (4·1 g.).

Cyclisation (cf. Hunsdiecker, *Ber.*, 1942, **75**, 455).—The above *meso*-diketone (6·4 g.) in dioxan (50 c.c.) was refluxed with potassium hydroxide (2 g.) in 50% aqueous ethanol (180 c.c.) for 5 hr., during which a cherry-red colour developed. Water was added, and the product taken up in ether, washed with water, and dried. Removal of the ether gave **4** : **5**-*di*-p-*methoxyphenyl*-**3**-*methylcyclopent*-**2**-*en*-**1**-*one*, m. p. 132—135° (4·8 g.), raised to 134—135° by recrystallisation from methanol, from which it separated in rectangular prisms (Found : C, 77·6; H, 6·5. $C_{20}H_{20}O_3$ requires C, 77·9; H, 6·5%). The *semicarbazone*, obtained in poor yield in aqueous ethanol, crystallised in pale yellow needles, m. p. 184° (Found : N, 11·6. $C_{21}H_{23}O_3N_3$ requires N, 11·5%).

The racemic diketone (5 g.) gave, on similar treatment with alcoholic potassium hydroxide (dioxan being omitted), the same *cyclo*pentenone (4·5 g.).

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The Preparation of Some Glucose Nitrates.

By D. O'MEARA and D. M. SHEPHERD.

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The removal of the ethylidene group from methyl **4** : **6**-*O*-ethylidene-β-D-glucopyranoside **2** : **3**-dinitrate and **3**-nitrate by acid hydrolysis is described. Methyl β-D-glucopyranoside **2** : **3**-dinitrate prepared by this method had a higher melting point than, but in all other respects was identical with, specimens of the **2** : **3**-dinitrate prepared by an earlier method. Methyl β-D-glucopyranoside **3**-nitrate was obtained as a monohydrate. The two known forms of methyl **4** : **6**-di-*O*-methyl-β-D-glucopyranoside were obtained and shown to consist of the anhydrous compound and the monohydrate respectively. The preparation of several new glucose nitrate derivatives is described.

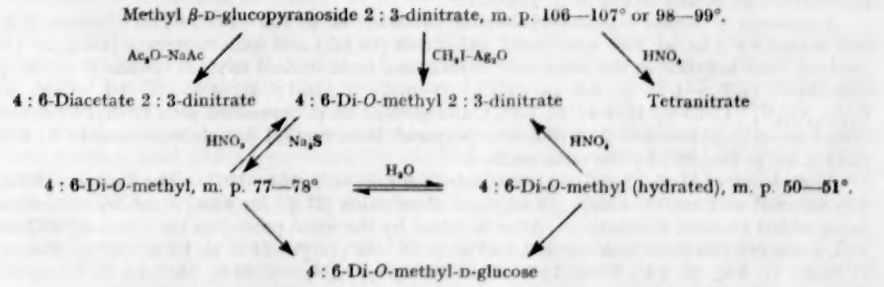
THREE methods have been described for the removal of ethylidene substituents from sugars: (*a*) acid hydrolysis (Ohle and Spencker, *Ber.*, 1928, **61**, 2387; Dewar and Fort, *J.*, 1944, 492); (*b*) acetolysis (Bell and Synge, *J.*, 1937, 1711); (*c*) nitration by fuming nitric acid in chloroform (Dewar and Fort, *J.*, 1944, 496). Method (*b*) suffers from the disadvantage that the ethylidene group is replaced by acetyl and acetoxyethyl substituents which must subsequently be removed by selective alkaline hydrolysis, while with method (*c*) two nitrate groups are introduced in place of the ethylidene group. Although method (*a*) removes the ethylidene group leaving two free hydroxyl groups, it has so far been found to be of limited applicability, since the presence of certain other substituents, particularly nitrate groups, renders the ethylidene group more resistant to hydrolysis (Bell and Synge, and Dewar and Fort, *locc. cit.*). Since we required considerable amounts of methyl β-D-glucopyranoside **2** : **3**-dinitrate and **3**-nitrate, which are normally prepared from the corresponding ethylidene derivatives in two stages by method (*b*) (Bell and Synge, *loc. cit.*), we re-investigated the direct acid hydrolysis of methyl **4** : **6**-*O*-ethylidene-β-D-glucopyranoside **2** : **3**-dinitrate and **3**-nitrate.

The first stage, condensation of acetaldehyde with methyl β-D-glucopyranoside to give methyl 4 : 6-*O*-ethylidene-β-D-glucopyranoside (Helferich and Appel, *Ber.*, 1931, **64**, 1841; Dewar and Fort, *J.*, 1944, 492), has hitherto been accomplished by treating paraldehyde with the glucoside in the presence of concentrated sulphuric acid, but the yields are rather variable owing to a side reaction which gives methyl 4 : 6-*O*-ethylidene-2 : 3-*O*-oxidodiethylidene-β-D-glucopyranoside. The required derivative has been obtained uncontaminated and in good yield by using acetaldehyde dimethyl acetal instead of paraldehyde.

When methyl 4 : 6-*O*-ethylidene-β-D-glucopyranoside 2 : 3-dinitrate was refluxed with sulphuric acid in aqueous acetone, it was found that >0·1N-acid had no effect, while concentrations greater than 1·0N not only removed the ethylidene group but tended to split the methyl glucoside group as well. However, a crystalline compound was obtained in good yield when 0·67N-sulphuric acid was used. While the analysis and optical rotation of the product agreed with those of the expected methyl β-D-glucopyranoside 2 : 3-dinitrate, the melting point was 106—107° compared with 96—98° reported by Bell and Synge (*loc. cit.*). The 2 : 3-dinitrate prepared in this laboratory by Bell and Synge's method melted at 98—99° alone, and at 99—101° when mixed with our product. Attempts at interconversion of the two compounds were unsuccessful.

A detailed comparison of the reactions (see scheme) of our product and Bell and Synge's compound indicated that chemically the two substances were identical. Methyl 4 : 6-di-*O*-methyl-β-D-glucopyranoside exists in interconvertible anhydrous (m. p. 77—78°) and hydrated (m. p. 50—52°) forms. Bell and Synge (*loc. cit.*) obtained the latter, and Dennison and McGilvray (*J.*, 1951, 1616) the former. Reeves (*J. Amer. Chem. Soc.*, 1949, **71**, 215) obtained forms of m. p. 52—55° and 67—68°, but his substances possibly consisted of partially hydrated material. All our specimens were readily re-nitrated to the 2 : 3-dinitrate, and on acid hydrolysis yielded the same parent sugar as shown by paper chromatography.

Methyl 4 : 6-*O*-ethylidene-β-D-glucopyranoside 3-nitrate was obtained from the 2 : 3-dinitrate by sodium iodide in pentan-2-one; the development of high pressures which occurs when acetone is used as solvent (Dewar and Fort, *loc. cit.*; Ansell and Honeyman, *J.*, 1952, 2778) was thus avoided.



The ethylidene group was removed from methyl 4 : 6-*O*-ethylidene-β-D-glucopyranoside 3-nitrate by boiling 0·67N-sulphuric acid, the product being a monohydrate of methyl β-D-glucopyranoside 3-nitrate which gave a triacetate. This monohydrate was identical with the 3-nitrate described by Dewar and Fort (*loc. cit.*).

Methyl β-D-glucopyranoside 2-acetate 3 : 4 : 6-trinitrate was readily obtained by the nitration of methyl 4 : 6-*O*-ethylidene-β-D-glucopyranoside 2-acetate 3-nitrate with fuming nitric acid in chloroform : it is polymorphic, though the unstable form was obtained only in the first experiment.

The trinitrate was preferentially de-acetylated by dilute alkali, to give methyl β-D-glucopyranoside 3 : 4 : 6-trinitrate.

3-*O*-Methyl-D-glucose tetranitrate was prepared from 3-*O*-methyl-D-glucose by fuming nitric–sulphuric acid; the high specific rotation suggests that the product is the α-anomer.

Experimental

Light petroleum had b. p. 60—80°.

Methyl 4 : 6-O-*Ethylidene*-β-D-*glucopyranoside*.—Concentrated sulphuric acid (2·5 ml.) was added dropwise, with stirring, to a suspension of methyl β-D-glucopyranoside (58 g.) in acetaldehyde dimethyl acetal (250 ml.). After being shaken for 48 hr., the mixture was filtered, and the solid residue washed with light petroleum and recrystallized twice from ethanol, giving needles (38 g.), m. p. 188—189°, $[\alpha]_D^{20}$ −79·4° (*c*, 1·9 in H_2O). Helferich and Appel (*loc. cit.*) give m. p. 189—190°, $[\alpha]_D^{22}$ −79·1°. No m. p. depression was observed on admixture with material prepared by Helferich and Appel's method.

Methyl 4 : 6-O-*Ethylidene*-β-D-*glucopyranoside* 2 : 3-*Dinitrate* (cf. Honeyman and Morgan, *Chem. and Ind.*, 1953, 1035).—To a suspension of the ethylidene derivative (10 g.) in acetic anhydride (25 ml.) at 0° was added an ice-cold solution of fuming nitric acid (20 ml.) in acetic anhydride (50 ml.). After being stirred for 5 min. at 0°, the mixture was poured into ice-water. The solid which separated crystallized from ethanol as plates (11 g.), m. p. 88—89°, alone or mixed with methyl 4 : 6-*O*-ethylidene-β-D-glucopyranoside 2 : 3-dinitrate prepared as described by Bell and Synge (*loc. cit.*).

Hydrolysis. To a solution of the dinitrate (12 g.) in acetone (96 ml.) were added water (48 ml.) and concentrated sulphuric acid (2·4 ml.). The solution was refluxed for 7 hr., cooled, and passed down a column of the anion-exchange resin Amberlite IR-4B (OH). When the neutral filtrate was distilled to remove all the acetone, a small amount of oil was precipitated. Alcohol was then added to redissolve the oil and the distillation continued until crystals separated. After cooling and filtration, these crystals (2·5 g.) were identified by mixed m. p. as unchanged ethylidene derivative. The filtrate was then evaporated to dryness and the residual syrup dissolved in chloroform. When dried and distilled, the chloroform extract yielded a syrup which crystallized on addition of light petroleum. Recrystallization of the product from chloroform–light petroleum gave needles (4·5 g.), m. p. 106—107°, $[\alpha]_D^{22}$ −20·8° (*c*, 1·8 in $CHCl_3$ containing 5% of acetone) (Found : C, 30·1; H, 4·6; N, 9·9; OMe, 11·3. Calc. for $C_7H_{12}O_{10}N_2$: C, 29·6; H, 4·2; N, 9·9; OMe, 10·9%). Bell and Synge (*loc. cit.*) record m. p. 96—98°, $[\alpha]_D^{20}$ −20·5°. A mixture of the above product with methyl β-D-glucopyranoside 2 : 3-dinitrate, m. p. 98—99°, prepared in this laboratory by Bell and Synge's method, had m. p. 99—101°.

Nitration of Methyl β-D-*Glucopyranoside Dinitrate, m. p.* 106—107°.—The dinitrate, on nitration by Honeyman and Morgan's method (*loc. cit.*), gave methyl β-D-glucopyranoside tetranitrate, m. p. and mixed m. p. 115—116°.

Acetylation of Methyl β-D-*Glucopyranoside Dinitrate, m. p.* 106—107°.—The dinitrate (2 g.) was heated for 2 hr. at 100° with acetic anhydride (10 ml.) and sodium acetate (1·6 g.). The product, after isolation in the usual way, crystallized from ethanol as stout needles (1 g.), m. p. 139—140°, $[\alpha]_D^{20}$ −4·7° (*c*, 3·8 in $CHCl_3$) (Found : C, 36·1; H, 4·6; N, 7·1. Calc. for $C_{11}H_{16}O_{12}N_2$: C, 35·9; H, 4·4; N, 7·6%), and gave no m. p. depression with methyl 4 : 6-di-*O*-acetyl-β-D-glucopyranoside 2 : 3-dinitrate prepared from methyl β-D-glucopyranoside 2 : 3-dinitrate, m. p. 98—99°, by the same method.

Methylation of Methyl β-D-*Glucopyranoside Dinitrate, m. p.* 106—107°.—The dinitrate (6·7 g.) was refluxed with methyl iodide (27 ml.) and silver oxide (27 g.) for 4 hr., some dry chloroform being added to assist dissolution. After isolation by the usual procedure the syrup crystallized and, when recrystallized from alcohol, had m. p. 52—53°, $[\alpha]_D^{22}$ −11·5° (*c*, 1·1 in $CHCl_3$) (Found : C, 34·6; H, 5·5; N, 9·8; OMe, 28·6. Calc. for $C_9H_{16}O_{10}N_2$: C, 34·6; H, 5·1; N, 9·0; OMe, 29·8%), and gave no m. p. depression with methyl 4 : 6-di-*O*-methyl-β-D-glucopyranoside 2 : 3-dinitrate prepared by methylation of methyl β-D-glucopyranoside 2 : 3-dinitrate under identical conditions.

Methyl 4 : 6-*Di*-O-*methyl*-β-D-*glucopyranoside*.—Methyl 4 : 6-di-*O*-methyl-β-D-glucopyranoside 2 : 3-dinitrate was denitrated as described by Bell and Synge (*loc. cit.*). Recrystallization of the product from ether gave long colourless needles, m. p. 77—78°, $[\alpha]_D^{18}$ −33·7° (*c*, 0·41 in $CHCl_3$) (Found : C, 48·9; H, 8·3; OMe, 40·8. Calc. for $C_9H_{18}O_6$: C, 48·6; H, 8·1; OMe, 41·8%).

When this compound, m. p. 77—78°, was left for 48 hr. in air, the m. p. fell to 50—52°. This *hydrate* had $[\alpha]_D^{18}$ −30·5° (*c*, 0·43 in $CHCl_3$) (Found : C, 45·6; H, 8·4; OMe, 38·1; loss in a vacuum over $CaCl_2$, 7·4. $C_9H_{18}O_6,H_2O$ requires C, 45·0; H, 8·3; OMe, 38·8; H_2O, 7·5%).

On nitration the hydrate, like the anhydrous compound, was converted into methyl 4 : 6-di-*O*-methyl-β-D-glucopyranoside 2 : 3-dinitrate, m. p. and mixed m. p. 52—53°.

Hydrolysis and Proof of Identity of Methyl 4 : 6-*Di*-O-*methyl*-β-D-*glucopyranoside from Various*

Sources.—Samples (50 mg.) of the hydrated and unhydrated forms of methyl 4 : 6-di-*O*-methyl-β-D-glucopyranoside derived from both the high- and the low-melting form of methyl β-D-glucopyranoside 2 : 3-dinitrate by the reactions shown in the scheme (p. 4233), were hydrolyzed at 90—95° in centrifuge tubes with N-hydrochloric acid (2 ml.) for 1 hr. Water (5 ml.) was added to each tube and the excess of acid neutralized with silver carbonate. After centrifuging, the supernatant liquids, suitably diluted, were subjected to paper chromatography. When sprayed with aniline oxalate the chromatograms showed one spot from each sample, having R_F in butanol–acetic acid–water (4 : 1 : 5 by vol.) 0·53, and in phenol–water (4 : 1 by wt.) 0·82.

Methyl 4 : 6-O-*Ethylidene*-β-D-*glucopyranoside* 3-*Nitrate.*—Methyl 4 : 6-*O*-ethylidene-β-D-glucopyranoside 2 : 3-dinitrate (10 g.), sodium iodide (20 g.), and pentan-2-one (70 ml.) were heated for 6 hr. on a boiling-water bath. The 3-nitrate, isolated as described by Dewar and Fort (*loc. cit.*), formed needles (4·1 g.), m. p. 147—148°, $[\alpha]_D^{19}$ −30·6° (*c*, 1·69 in $CHCl_3$).

Hydrolysis. To a solution of this nitrate (6·2 g.) in acetone (50 ml.) were added water (25 ml.) and concentrated sulphuric acid (1·25 ml.). After 3 hours' refluxing the solution was neutralized with Amberlite IR-4B(OH), and the acetone removed by vacuum-distillation. Crystals separated from the aqueous residue which was then cooled and filtered. The crystals (1·8 g.) were unchanged ethylidene derivative (mixed m. p.). Evaporation of the filtrate gave a syrup which crystallized and, when recrystallized once from water and once from alcohol–ether–light petroleum, yielded prisms of a *hydrate*, m. p. 102—104° (soften at 95°), $[\alpha]_D^{19}$ −16·1° (*c*, 0·53 in EtOH) (Found, for material dried over $CaCl_2$: C, 33·2; H, 5·8; N, 5·7. $C_7H_{13}O_8N,H_2O$ requires C, 32·8; H, 5·8; N, 5·5%). The compound gave no m. p. depression with methyl β-D-glucopyranoside 3-nitrate prepared by Dewar and Fort (*loc. cit.*). When dried in a vacuum over P_2O_5 at 40°, the monohydrate slowly lost water (loss, 6·8. $C_7H_{13}O_8N,H_2O$ requires 7·0%) to give the anhydrous *compound* (Found: C, 35·1; H, 6·0. $C_7H_{13}O_8N$ requires C, 35·1; H, 5·4%).

Methyl β-D-*Glucopyranoside* 2 : 4 : 6-*Triacetate* 3-*Nitrate.*—Methyl β-D-glucopyranoside 3-nitrate (2·2 g.) was heated for 2 hr. at 100° with acetic anhydride (11 ml.) and sodium acetate (1·8 g.). After isolation in the usual way the *triacetate* 3-*nitrate* crystallized from ethanol as needles, m. p. 61—62°, $[\alpha]_D^{20}$ −20° (*c*, 1·35 in $CHCl_3$) (Found: C, 42·8; H, 5·2; N, 3·9. $C_{13}H_{19}O_{11}N$ requires C, 42·7; H, 5·2; N, 3·9%).

Methyl β-D-*Glucopyranoside* 2-*Acetate* 3 : 4 : 6-*Trinitrate.*—Methyl 4 : 6-*O*-ethylidene-β-D-glucopyranoside 2-acetate 3-nitrate (4 g.) (Dewar and Fort, *loc. cit.*) was nitrated with fuming nitric acid in chloroform, the product being isolated in the usual way. The acetate *trinitrate* crystallized from ethanol as needles, m. p. 57—58°, $[\alpha]_D^{19}$ −7·5° (*c*, 0·75 in $CHCl_3$) (Found: C, 29·2; H, 3·7; N, 10·8. $C_9H_{13}O_{13}N_3$ requires C, 29·1; H, 3·5; N, 11·3%).

In all later preparations the product had m. p. 66—67°, $[\alpha]_D^{20}$ −8·4° (*c*, 2·486 in $CHCl_3$) (Found: C, 29·8; H, 3·6; N, 11·5%). A mixture of the two forms had m. p. 66—67°.

Methyl β-D-*Glucopyranoside* 3 : 4 : 6-*Trinitrate.*—The above product (2·2 g.) was dissolved in chloroform (25 ml.) and anhydrous methanol (25 ml.) containing sodium (0·03 g.). After 2 hr. glacial acetic acid (0·08 ml.) was added, and the solvents were distilled off, leaving a syrup from which a solid (0·5 g.) separated on addition of a little chloroform. *Methyl* β-D-*glucopyranoside* 3 : 4 : 6-*trinitrate* crystallized from chloroform as needles, m. p. 117—118°, $[\alpha]_D^{19}$ +14° (*c*, 3·1 in $CHCl_3$) (Found: C, 25·2; H, 3·5; N, 11·4. $C_7H_{11}O_{12}N_3$ requires C, 25·5; H, 3·3; N, 12·7%).

3-O-*Methyl*-D-*glucose Tetranitrate.*—3-*O*-Methyl-D-glucose (9 g.) (Levene and Meyer, *J. Biol. Chem.*, 1922, **54**, 805) was dissolved in fuming nitric acid (90 ml.) at 0°; and concentrated sulphuric acid (180 ml.) also at 0° was added during 20 min. with stirring and ice-cooling. After 1 hr. chloroform (150 ml.) was added, and the mass stirred vigorously. The chloroform layer was separated and the product isolated in the usual way as a syrup which soon solidified. 3-O-*Methyl*-D-*glucose tetranitrate* crystallized from methanol as prisms, m. p. 99—100°, $[\alpha]_D^{23}$ +140·3° (*c*, 2·1 in MeOH) (Found: C, 22·6; H, 2·7; N, 15·1. $C_7H_{10}O_{14}N_4$ requires C, 22·5; H, 2·7; N, 15·0%).

We are grateful to Dr. E. S. Steele for providing samples for mixed melting points. One of us (D. O'M.) is indebted to the Wellcome Research Foundation for a grant.

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Cinnolines and Other Heterocyclic Types in Relation to the Chemotherapy of Trypanosomiasis. Part X. The Quaternisation of 4-Aminocinnolines.*

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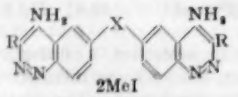
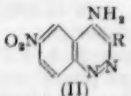
4-Aminocinnolines with methyl iodide in alcohol yield mixtures of two series of quaternary salts in which only the ring nitrogen atoms are involved. The evidence that $N_{(1)}$ is the basic centre in the cinnoline series is reviewed and is supported by degradation studies, but it also has been clearly shown that $N_{(1)}$ is not exclusively the basic centre. Evidence that $N_{(2)}$ may be involved in quaternary salt formation is reported.

Earlier parts of this series have described the synthesis of bis-heterocyclic salts (as I) for test against *T. congolense* in connection with the theory set out in Part I (Keneford, Lourie, Morley, Simpson, Williamson, and Wright, *J.*, 1952, 2595) that the activity of crude solutions of reduced 4-amino-6-nitrocinnoline methiodides (II; R = H or Me) is due to the formation of azo-compounds (as I; X = –N=N–). An alternative interpretation of these results arose from the isolation (Part I, p. 2601) of two active isomeric salts from the quaternisation of 4-amino-6-nitrocinnoline. The possibility that high activity would be associated with a reduction product of only one of these isomers was supported by the appreciably higher activity of one of the isomeric salts isolated from the quaternisation of 4 : 4′-diamino-6 : 6′-azocinnoline (McIntyre and Simpson, *J.*, 1952, 2606). This result emphasised the importance of investigating the nature of the isomerism in the simple cinnolinium salts.

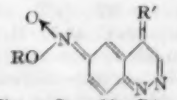


(I)



(II)

MeI



(III): *a*, R = Me, R′ = O.
b, R = H, R′ = NH.

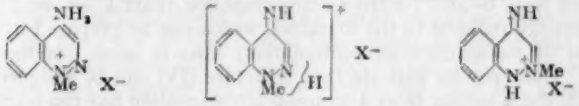
One of the 4-amino-6-nitrocinnolinium salts was readily obtained as massive red needles by recrystallisation from water but the other isomer was separated initially by a tedious hand-separation of the small yellow prisms, seeding of an aqueous solution being ineffective. The variable temperatures at which the isomers melted with decomposition could be standardised (Kofler block) at 222° and 240°, respectively, and the distinct nature of the salts was confirmed by reduction (see below), by spectroscopy (Professor R. A. Morton kindly determined the ultraviolet absorptions), and by paper chromatography. A mixture of *tert.*-butyl alcohol–water–hydrochloric acid was adopted for the chromatography and, in our opinion, this technique provides the best criterion of purity for this class of compound. Large-scale separations, which failed on a cellulose column, were achieved by removal of the bulk of one isomer by recrystallisation from water, conversion of the remainder into methochlorides, and recrystallisation of this mixture from the solvent mixture used for chromatography. This procedure was successful also with the other mixtures of salts which were investigated.

In the 4-amino-6-nitrocinnoline series the task of assigning structures to these compounds was complicated by the possibilities of tautomerism involving the hetero-ring and the 6-nitro-group. Attention was therefore directed to 4-amino- and 4-amino-7-chlorocinnoline which also gave isomeric quaternary salts.

The possibility that one of the salts arose by alkylation of the 4-amino-group was next considered. 4-Methylaminocinnoline, prepared by the action of methylamine on a solution of 4-chlorocinnoline in phenol, formed a hydrochloride which was different from either of the quaternary salts of 4-aminocinnoline. Analogous results were obtained in the 4-amino-6-nitrocinnoline series. Thus the 4-amino-group is not involved in the quaternisation,

* Part IX, *J.*, 1954, 2023.

this behaviour being similar to that in the acridine series where the 5-amino-group has been shown not to add a proton (Craig and Short, *J.*, 1945, 419). Thus only the ring-nitrogen atoms are involved and each of the two isomeric salts can have one only of the following structures, where the proton in (V) may be attached to $N_{(1)}$ or $N_{(2)}$.



(IV) (V) (VI)

Evidence for Quaternisation on $N_{(1)}$.—This may be summarised as follows: (1) The calculations of Longuet-Higgins and Coulson (*J.*, 1949, 971) give the net charges at each nitrogen atom as $N_{(1)} = -0{\cdot}249$ and $N_{(2)} = -0{\cdot}203$. These figures would be conclusive were it not for the uncertainty in the Coulomb integral y_s in the equation $1 - q_r = -\Sigma_s x_{r,s}\, y_s$ where $1 - q_r$ is the net positive charge at atom r ($N_{(1)}$, $N_{(2)}$) in the cinnoline nucleus (Longuet-Higgins and Coulson, *loc. cit.*) and the fact that the basicity is probably dependent on the change of resonance integral in the C–N bonds on quaternisation. (2) Reactions of the methyl group in 4-methylcinnolines occur more readily than the corresponding reactions of 3-methylcinnoline (Alford and Schofield, *J.*, 1953, 1811) and in general the reactivity of substituents on $C_{(4)}$ is greater than that at other positions. (3) The observation that reduction of 4-phenylcinnolines yields 3-phenylindoles and ammonia (Atkinson and Simpson, *J.*, 1947, 1649), and Barltrop and Taylor's report (*J.*, 1951, 109) that catalytic hydrogenation of heterocyclic quaternary salts did not result in fission of the quaternary alkyl group, suggested a study of the catalytic hydrogenation of the cinnolinium salts. If the reaction had proceeded smoothly and in good yield the use of labelled nitrogen would have shown unambiguously the position of the basic centre. Unfortunately this has not yet been realised but from the reduction of cinnoline methiodide a good yield of ammonia, uncontaminated with methylamine, and a low yield of 1-methylindole were obtained. (4) 4-Acetamido-8-nitrocinnoline did not react with methyl iodide under the usual conditions (see experimental section). This fact will be discussed below.

On the basis of this evidence it is suggested that structure (IV) represents one of the isomeric quaternary salts.

Studies connected with the Ultraviolet Absorption Spectra of the Cinnolinium Salts.—Hearn, Morton, and Simpson (*J.*, 1951, 3325) have discussed the ultraviolet absorption spectrum of cinnoline and have suggested that the weak band at 3900 Å is due to the –N=N– chromophore. Burawoy (*J.*, 1937, 1865) studied the absorption spectrum of azobenzene and showed that this compound absorbed 100 times more strongly in acidic media (where, presumably the chromophore $-N{:}NH^{+}-$ was being measured) than in *cyclo*hexane. It is known (van Allan and Allen, *J. Amer. Chem. Soc.*, 1951, **73**, 5850) that 4-phenylcinnolines do not absorb strongly in this region and it has been shown in this work that 4-methoxy-7-nitrocinnoline is similar in this respect (Fig. 1). Thus intense light absorption in this region of the spectrum is associated with structural changes in the –N=N– group. It was expected, therefore, that differences in structure in this part of the molecule and in particular differences between $-{}^{+}\overset{1}{N}=\overset{2}{N}-$ (IV), $-{}^{+}\overset{1}{N}H-\overset{2}{N}=$ (V), and $-\overset{1}{N}H-\overset{2}{N}^{+}=$ (VI) should be shown in this band. This has proved to be the case. Two types of spectrum have been observed, each corresponding to one of the salts obtained on quaternisation of a 4-aminocinnoline (Fig. 2). An apparent exception was the spectrum of the salt, m. p. 222° (decomp.), derived from 4-amino-6-nitrocinnoline, but this was satisfactorily explained, and the structure of the salt represented as the 1-methiodide of (III*b*), when it was observed that the spectrum of tetrahydro-6-*O*-methyl*aci*nitro-4-oxocinnoline (III*a*) (Schofield and Simpson, *J.*, 1945, 512; Hearn, Morton, and Simpson, *loc. cit.*) was almost identical (Fig. 1). These results have permitted classification of the salts as α and β, those exhibiting a double and a single peak respectively in the 3000—4000 Å band.

Acetylation Experiments and Related Topics.—Comparative experiments on the acetylation of the α- and β-isomers with acetyl chloride substantiated the classification, for only

the former were acetylated, yielding the products obtained on quaternisation of 4-acetamidocinnolines. Only one quaternary salt was obtained from this reaction, as was shown by paper chromatography. Acid hydrolysis of the 4-acetamidocinnolinium salts provided the corresponding α-4-aminocinnoline salts in theoretical yield. Furthermore, the α-salts derived from 6- and 7-nitro-4-aminocinnoline (Part I, *loc. cit.*; Part VIII, *J.*, 1954, 1381) are readily reduced to the diamines, which can be prepared by an alternative route; reduction of β-4-amino-6-nitrocinnolinium salts is more complex and is being studied further. These results indicate that structure (IV) can be assigned to the α-salts and that although the α-isomer from 4-amino-6-nitrocinnoline has the nitronate structure (III*b*), this, too, is quaternised on $N_{(1)}$. Reference was made earlier to the recovery of 4-acetamido-8-nitrocinnoline after prolonged refluxing with ethanolic methyl iodide, in spite of the appreciable solubility of the base in the hot reagent. The importance of the steric effect on the quaternisation reaction is well known (von Braun and Kruber, *Ber.*, 1913, **46**, 3470; Thomas, *J.*, 1913, 594; Meer and Polyani, *Z. phys. Chem.*, 1932, **164**, 1319; Evans,

FIG. 1. FIG. 2. FIG. 3.

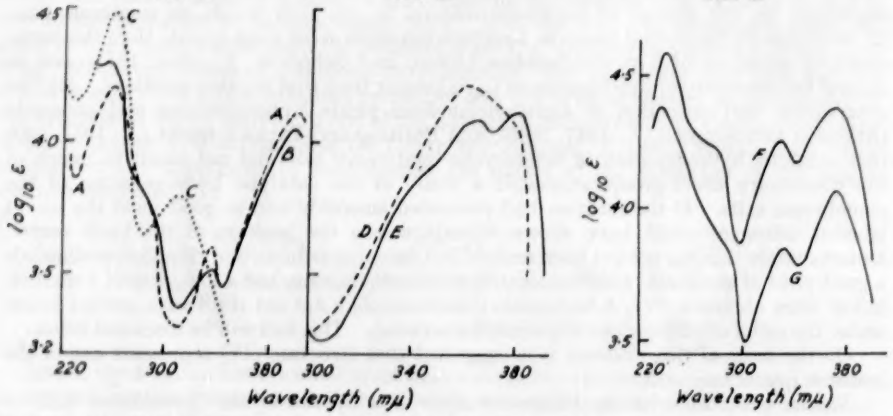


FIG. 1. *Absorption spectra of* (*A*) *tetrahydro-6-*(O-*methyl*ac*initro*)-4-*oxocinnoline*, (*B*) 4-*amino*-6-*nitrocinnoline methiodide* (α), *m. p.* 222°, *and* (*C*) 4-*methoxy*-7-*nitrocinnoline.*

FIG. 2. *Absorption spectra of* (*D*) *the* β-*methochloride and* (*E*) *the* α-*methiodide of* 4-*amino*-7-*chlorocinnoline.*

FIG. 3. *Absorption spectra of* (*G*) 4-*amino*-6-*nitrocinnoline* β-*methiodide, m. p.* 240°, *and* (*F*) *the dimer, m. p.* 233—234°.

Watson, and Williams, *J.*, 1939, 1348; Brown and Fried, *J. Amer. Chem. Soc.*, 1943, **65**, 1843; Brown and Eldred, *ibid.*, 1949, **71**, 445) and particularly in the analogous 8-nitroquinoline series (Decker, *Ber.*, 1891, **24**, 1984; 1903, **36**, 261; 1905, **38**, 1144); hence this result is regarded as implicit proof, not only that the basic centre of substituted cinnolines is $N_{(1)}$, but also that (IV) represents the structures of the α-isomers.

Degradation of the 4-*Aminocinnolinium Salts.*—Degradation was studied in three sets of conditions: (*a*) hot water, (*b*) ice-cold N-alkali, and (*c*) refluxing N-alkali until no more basic gases were evolved. Most of the experiments listed under (*a*) and (*c*) were carried out in a micro-Kjeldahl apparatus and the basic gases were analysed by a method based on an observation by François (*J. Pharm. Chim.*, 1907, **25**, 517) that yellow mercuric oxide selectively absorbs ammonia in the presence of methylamine. No basic gas other than ammonia was detected, thus confirming the view that the 4-amino-group was not involved in the quaternisation.

(a) *Treatment with boiling water.* Most of the quaternary salts studied were recovered unchanged when their aqueous solutions were refluxed for 24 hr. However, the β-isomers having a 6- or a 8-nitro-group (the 7-nitro-salt was not isolated) were unstable and yielded

an equimolecular quantity of ammonia and the corresponding 1-methyl-4-cinnolones under these conditions. The nitro-group was the main cause of the ready decompositon, for the parent unquaternised amines were also converted into the corresponding 4-hydroxy-compounds in boiling water.

(b) *Treatment with ice-cold* N-*alkali.* When a slurry of a quaternary salt was treated under these conditions the solid slowly dissolved and an orange precipitate separated. The analysis results for the more stable of these compounds indicated that one molecule of water had been lost; the ultraviolet absorption spectra (cf. Fig. 3) were identical in every respect with those of the parent quaternary salt except that the molecular extinction coefficients observed were exactly twice those of the salt. This was not observed when the spectra of the salts were measured in dilute alkali and it was therefore concluded that the anhydro-bases were dimeric. The dimer from β-4-amino-6-nitro-4-cinnolinium salts rapidly lost ammonia in boiling water and 1-methyl-6-nitro-4-cinnolone was precipitated in quantitative yield. On treatment with dilute acid the dimers were converted into the parent quaternary salts.

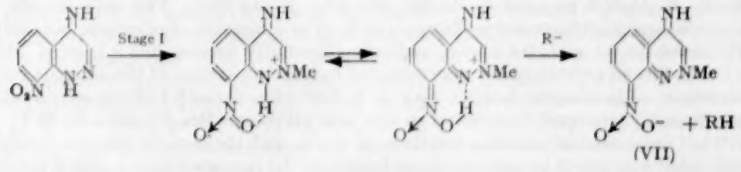
(c) *Treatment with boiling* N-*alkali.* α-4-Amino-6-nitrocinnolinium salts decomposed rapidly with the formation of alkali-soluble tars, in agreement with the representation as salts of (III*b*) and the behaviour of the nitronate (III*a*) under similar conditions (Keneford *et al.*, *J.*, 1950, 1104). The other α-isomers provided one molecular proportion of ammonia and a moderate yield of the 1-methyl-4-cinnolone, the mixtures exhibiting a variety of colour changes (brown, green, and blue).

The quaternary salt obtained from 4-amino-8-nitrocinnoline behaved unusually when treated under the three sets of conditions, for in boiling water ammonia was slowly evolved and 4-hydroxy-8-nitrocinnoline formed. Treatment with cold alkali yielded an extremely unstable dimeric anhydro-base which lost ammonia and formed an intractable tar in warm water; with hot alkali only tars were obtainable.

The reaction of the β-isomers is complex and is still under investigation, although the formation of dimers (above) can be explained more readily by assuming quaternisation to have occurred on $N_{(2)}$.

Evidence for Quaternisation on $N_{(2)}$.—During a study of the effect of alkylating agents in neutral solution on the system NHR–NR′R″ Singh (*J.*, 1913, 604) found that the tertiary nitrogen atom was invariably alkylated. This confirmed in a more general manner Fischer and Tafel's earlier finding (*Annalen*, 1885, **227**, 321) that on quaternisation in neutral solution indazole derivatives were alkylated on $N_{(2)}$. Since the β-4-amino-cinnolinium salts arise from the 4-imino-tautomers the two systems are analogous and this work may be taken as supporting the hypothesis that quaternisation takes place in the 4-aminocinnolines on $N_{(2)}$.

The aqueous decomposition of the quaternary salt derived from 4-amino-8-nitro-cinnoline is slow in comparison with that of the β-6-nitro-analogue and the isolation of 4-hydroxy-8-nitrocinnoline as the only product requires that the proposed mechanism should involve the fission of the C–N bond. The smooth quaternisation of 4-amino-8-nitrocinnoline to give only one product contrasts with the recovery of 4-acetamido-8-nitro-cinnoline in high yield after the same treatment and it is difficult to avoid the conclusion that the reaction proceeds as in stage I below. This is supported by very slow quaternis-



(VII)

ation of 4-amino-3-methyl-8-nitrocinnoline (Part II, *J.*, 1952, 2597), for in this case both ring-nitrogen atoms are sterically hindered.

A similar explanation is advanced for the rupture in 4-amino-8-nitrocinnolinium iodide

of the C–N bond referred to above, for the shift from $N_{(2)}$ to $N_{(1)}$ will be hindered by the 8-nitro-group. The relatively slow degradation of this salt can therefore be explained, for the initial removal of the proton from $N_{(1)}$ will be hindered, and the energy required to rupture the C–N bond will not be gained by its subsequent formation at $N_{(1)}$. The instability of this salt and its anhydro-base can also be understood since on being warmed in alkaline solution the nitronate (VII) would be expected to decompose.

Experimental

M. p.s were determined on the Kofler block, set at the maximum heating rate up to 10° below the m. p. (most important when there was decomposition), and then at 3° per min.

Ultraviolet absorption spectra were determined on a "Unicam" spectrophotometer and $\lambda_{max.}$ values are given below after the corresponding analyses. The compounds were dissolved in alcohol and/or water and determinations carried out in the same 2-mm. silica cells. The instrument was checked at frequent intervals against 4-hydroxy-8-nitrocinnoline, the spectrum of which was determined for us initially by Professor R. A. Morton.

Paper chromatography was carried out with "Whatman No. 1" paper and a mixture of *tert.*-butyl alcohol (70 c.c.), 6N-hydrochloric acid (1·65 c.c.), and water (to 100 c.c.). The solvent was allowed to flow down the paper from an elevated trough set in an inverted bell-jar, the latter being closed by greased plate glass. After *ca.* 50 hr. the paper was dried in air and examined before an ultraviolet lamp fitted with a "Corning 9863" filter (Holiday and Johnson, *Nature*, **1949**, **163**, 216) which transmits light of 230—400 mμ. The R_F values of quaternary salts are given below after the corresponding analyses. Variation in the concentration of hydrochloric acid (from 0·1N, as specified above, to 1·6N) had little effect on the R_F values. Results with other solvent mixtures were unsatisfactory.

4-Acetamido-6-nitrocinnoline Methiodide.—(*a*) A solution of the cinnoline (2 g.) in ethanol (80 c.c.) was refluxed for 5 hr. with methyl iodide (20 c.c.), and the crystalline precipitate [2·3 g.; m. p. 189—190° (decomp.)] collected. The pure *salt* (m. p. unchanged) crystallised from water in dark red needles (Found: C, 35·1; H, 3·15; N, 15·1; I, 35·3. $C_{11}H_{11}O_3N_4I$ requires C, 35·3; H, 3·0; N, 15·0; I, 33·9%).

(*b*) An intimate mixture of the cinnoline (0·5 g.) and methyl toluene-*p*-sulphonate (0·5 g.) was heated in an oil-bath to 100° (in 8 min.) and then kept at 100—108° for 7 min. The mixture was dissolved in warm water, cooled, and extracted with ether, and the ether-free aqueous layer was treated with saturated potassium iodide solution. The crude methiodide [0·34 g.; m. p. 183° (decomp.)] crystallised from water to give material (0·2 g.) identical (mixed m. p.) with that described in (*a*) (Found: C, 34·8; H, 3·3; N, 14·6; I, 35·5%). The yield by this method is considerably lower if slightly impure material is used.

Hydrolysis of the acetamido-salt (0·75 g.) by refluxing N-hydrochloric acid (24 c.c.) for 1 hr. and treatment of the cold solution with potassium iodide gave *4-amino-6-nitrocinnoline methiodide* (α) (0·6 g.) which crystallised from water as deep red prisms, m. p. 222° (decomp.) (Found: C, 32·6; H, 2·85; N, 16·2; I, 43·85. $C_9H_9O_2N_4I$ requires C, 32·6; H, 2·7; N, 16·9; I, 38·2%), $\lambda_{max.}$ 2550, 3370, 3980 Å (ε 20,000, 3300, and 11,100), R_F 0·71.

Quaternisation of 4-Amino-6-nitrocinnoline.—(*a*) Methyl toluene-*p*-sulphonate and the cinnoline (2 g. of each) were heated together to 105° during 5 min., then kept at 100—105° for 5 min., digested with boiling water (28 c.c.), and filtered hot. The residue [0·4 g.; m. p. 210—215° (decomp.)] was recrystallised (carbon) three times from water, to give golden prismatic needles of the *α-methotoluene-*p*-sulphonate* (90 mg.), m. p. 254° (decomp.) (Found: C, 50·8; H, 4·35; N, 13·9. $C_{16}H_{16}O_5N_4S$ requires C, 51·05; H, 4·3; N, 14·9%). The cold filtrate yielded crystals which separated from water (32 c.c.; carbon) as a mixture of prismatic needles (0·7 g.), identical (mixed m. p.) with the above, and colourless fluffy needles (0·3 g.), m. p. 263° (slow decomp.); the former crystals alone were collected by gentle warming of the aqueous suspension before filtration. The isomeric β-*salt* (0·2 g.), m. p. 268° (slow decomp.) (depressed on admixture with the α-isomer), separated from water in fine pale yellow needles (Found: C, 50·1; H, 4·0; N, 14·35%). Treatment of aqueous solutions of the α- and the β-methotoluene-*p*-sulphonates with a saturated solution of potassium iodide furnished the corresponding α- and β-iodide, m. p. 222° (decomp.) and 240° (decomp.), respectively.

(*b*) 4-Amino-6-nitrocinnoline (1 part), ethanol (10 parts), and methyl iodide (3 parts) were refluxed together for 3—5 hr. and the crude product was collected after cooling. Recrystallisation from water gave a mixture of thick red needles and golden prismatic needles from which

the former were isolated by cooling the solution very slowly and decanting the supernatant liquid at the first sign of formation of the latter type of crystal. Further recrystallisation of the red needles furnished the pure α-methiodide, m. p. and mixed m. p. 222° (decomp.). Repetition of this procedure with hand-separation of the larger crystals of each type yielded the pure β-*methiodide*, m. p. 240° (decomp.) (Found : C, 32·95; H, 2·9; N, 16·7; I, 38·3%), $\lambda_{max.}$ 2365, 2775, 3310, and 3725 Å (ε 24,000, 8710, 7080, and 11,800 respectively), R_F 0·49. The instability of this salt towards hot water (see below) precludes prolonged fractional crystallisation.

A better method of separation involved isolation of the bulk of the α-methiodide as already described, followed by agitation of the mother-liquors (including the residue obtained by evaporation of the alcoholic reaction filtrate) with freshly precipitated, acid-free silver chloride for several hours at room temperature. The filtrate was evaporated to dryness in a desiccator, and to a solution of the residue (*x* g.) in warm water (14*x* c.c.) was added *tert.*-butyl alcohol (35*x* c.c.) containing 6N-hydrochloric acid (0·8*x* c.c.). The crystalline precipitate was subjected to the same procedure until chromatographically pure. Pure β-4-*amino*-6-*nitrocinnoline methochloride*, m. p. 305° (decomp.), crystallised from water in pale yellow needles and was identical with a sample prepared from the β-methiodide and silver chloride (Found : C, 44·65; H, 3·85; N, 23·5; Cl, 15·3. $C_9H_9O_2N_4Cl$ requires C, 44·9; H, 3·8; N, 23·3; Cl, 14·7%). The α-*methochloride*, m. p. 240° (decomp.), was similarly prepared from the α-methiodide (Found : C, 42·95; H, 4·35; N, 21·4; Cl, 14·1. $C_9H_9O_2N_4Cl,H_2O$ requires C, 41·8; H, 4·3; N, 21·65; Cl, 13·7%).

Quaternisation of 4-*Aminocinnoline*.—This was carried out as described above for the 6-nitro-derivative with the improved method of separation of the isomeric salts. 4-Aminocinnoline (13 g.) gave a crude solid product (20 g.; m. p. 224—240°) which by recrystallisation (3 times) from absolute ethanol furnished yellow prismatic needles of the pure α-*methiodide*, m. p. 258° (9·8 g.) (Found : C, 37·95; H, 3·85; N, 14·55; I, 43·75. $C_9H_{10}N_3I$ requires C, 37·65; H, 3·5; N, 14·6; I, 44·2%), $\lambda_{max.}$ 2150, 3550, and 3700 Å (ε 44,700, 13,200, and 13,800 respectively), R_F 0·72. The derived α-methochloride, m. p. 261°, separated as colourless, silky needles from ethanol. Evaporation of all mother-liquors to dryness, conversion of the mixed salt into chlorides, and treatment (once) with acidified aqueous *tert.*-butyl alcohol as above yielded the pure β-*methochloride*, m. p. 291° (3·8 g.), which formed massive colourless prismatic needles from ethanol (Found : C, 54·8; H, 5·05; N, 20·85; Cl, 17·7. $C_9H_{10}N_3Cl$ requires C, 55·2; H, 5·1; N, 21·4; Cl, 18·1%), $\lambda_{max.}$ 2135 and 3590 Å (ε 3700 and 2400 respectively), R_F 0·68.

Quaternisation of 4-*Amino*-7-*chlorocinnoline*.—When the separation given above was used, the base (3 g.) provided the methiodide (2·3 g.), m. p. 274° (slow decomp.), identical (mixed m. p.) with the compound, m. p. 282—283°, described in Part II (*loc. cit.*) (the difference in m. p. is due to the different rates of heating), $\lambda_{max.}$ 2240, 2800, 2900, 3650, and 3810 Å (ε 38,700, 6920, 6110, 12,200, and 13,200 respectively), R_F 0·78. The mother-liquors yielded, in the usual manner, the pure β-*methochloride*, m. p. 320° (decomp.), which separated from water in colourless prismatic needles (Found : C, 46·9; H, 3·8; N, 18·25; Cl, 31·75. $C_9H_9N_3Cl_2$ requires C, 47·0; H, 3·9; N, 18·3; Cl, 30·8%), $\lambda_{max.}$ 2195, 2410, 2700, 3600 Å (ε 27,200, 17,400, 12,600, and 16,500), R_F 0·64.

4-*Methylamino*-6-*nitrocinnoline Methiodide*.—This was prepared in the usual manner from the base (see later) and methyl iodide in refluxing ethanol. The *salt*, m. p. 222° (decomp.), separated as red needles from water (Found : C, 35·3; H, 3·15; N, 15·8; I, 38·35. $C_{10}H_{11}O_2N_4I$ requires C, 34·7; H, 3·2; N, 16·2; I, 36·7%). Alkaline decomposition gave a theoretical yield of methylamine, identified as picrate.

Acetylation of Cinnolinium Chlorides.—The salt (0·3 g.) was refluxed in "AnalaR" acetyl chloride (15 c.c.) until no further hydrogen chloride was given off. (With the β-salts no appreciable evolution occurred during 5 hr.). The excess of acetyl chloride was removed under reduced pressure and the residual solid was recrystallised from ethanol. Paper chromatograms from solutions of the crude and the pure products were examined and only spots representing the quaternary salts and/or their acetyl derivatives were observed. Acetyl derivatives of the following metho-salts were prepared : 4-*amino*-, m. p. 264° (Found : C, 51·2; H, 5·5; N, 17·2. $C_{11}H_{12}ON_3Cl,H_2O$ requires C, 51·7; H, 5·5; N, 16·4%), and 4-*amino*-7-*chloro-cinnoline methochloride*, m. p. 275° (Found : C, 48·2; H, 4·0; N, 14·9. $C_{11}H_{11}ON_3Cl_2$ requires C, 48·5; H, 4·1; N, 15·4%), and 4-amino-7-nitrocinnoline methiodide, m. p. and mixed m. p. 189°.

Quantitative Separation of Ammonia and Methylamine.—The mixture of amines (equiv. to *n* c.c. of 0·1N-acid) was shaken in a light-proof bottle for 2 hr. with mixed aqueous solutions of sodium carbonate (5 c.c.; 30%) and sodium hydroxide (5 c.c.; 20%) in which was suspended yellow mercuric oxide (*n*/10 g.). The bottle was opened in red light and the contents were filtered through a sintered-glass funnel (porosity 3) into a Buchner flask, connected to the pump through two acid-traps. The filtrate and acid from the traps were transferred to a Kjeldahl

apparatus, made strongly alkaline with sodium hydroxide solution (20%), and distilled in a stream of nitrogen for 1 hr. into two traps in series (each containing *n* c.c. of 0·1N-acid) for estimation in the usual manner. The Kjeldahl apparatus was tested with "AnalaR" ammonium chloride, the ammonia estimated being between 99·5 and 100% of the theoretical value. The following reproducible figures show the accuracy obtainable with "synthetic mixtures" of methylamine (previously purified by shaking with yellow mercuric oxide) and ammonia (from "AnalaR" ammonium chloride). Experiments 2 and 4 represent the limits of accuracy of the method.

Expt. no.	1	2	3	4
Titre of mixture	35·45	40·00	56·00	23·25
Titre of NH_2Me	15·10	0·70	54·9	23·20
Theor. titre of NH_2Me	15·10	0·77	*	23·15

* Commercial "methylamine."

Alkaline Decomposition of Cinnoline Quaternary Salts.—(*a*) The salt was dissolved in water (10—20 parts) and boiled in the micro-Kjeldahl apparatus. The ammonia liberated was estimated as usual and the remaining solution examined on a paper-chromatogram. Most of the salts studied were stable (to 18 hours' refluxing); β-4-amino-6-nitrocinnoline metho-salts gave (after 2½ hr.) 1-methyl-6-nitro-4-cinnolone, m. p. and mixed m. p. 190° (Found: C, 52·55; H, 3·35; N, 21·5. Calc. for $C_9H_7O_3N_3$: C, 52·7; H, 3·4; N, 20·5%). 4-Amino-8-nitrocinnoline methiodide gave 4-hydroxy-8-nitrocinnoline.

(*b*) A solution of the salt (0·5 g.) in warm water (10 c.c.) was rapidly cooled to 5° and the suspension made alkaline by dropwise addition of sodium hydroxide solution. The precipitate was washed with water and dried *in vacuo* over concentrated sulphuric acid. β-4-Amino-6-nitrocinnolinium salts gave the *anhydro-base*, m. p. 230—231°, which separated from ethanol in golden needles (Found: C, 53·5; H, 2·9; N, 28·0. $C_9H_6O_2N_4$ requires C, 52·9; H, 3·95; N, 27·4%). 4-Amino-8-nitrocinnoline methiodide gave an unstable orange solid, m. p. 64° (decomp.).

(*c*) A solution of the salt (0·5 g.) in warm water (10 c.c.) was refluxed with 2N-sodium hydroxide (5 c.c.) for a short time and the precipitate (if any) filtered off after cooling. The β-6-nitro-salts gave the *N*-methyl 4-cinnolones as in (*a*), the corresponding α-salts giving only tars.

4-*Acetamido*-8-*nitrocinnoline.*—The amino-compound (0·4 g.) was refluxed with acetic anhydride (4 c.c.) for 30 min. and the suspension (formed after initial solution) cooled and diluted with ether (100 c.c.). The solid (0·4 g.; m. p. 287—288°), recrystallised from ethyl methyl ketone, gave almost colourless needles of the pure *acetyl derivative*, m. p. 291—292° (Found: C, 52·25; H, 3·65; N, 24·05. $C_{10}H_8O_3N_4$ requires C, 51·7; H, 3·45; N, 24·1%).

4-*Methoxy*-7-*nitrocinnoline.*—A solution of 4-chloro-7-nitrocinnoline (1·5 g.) in benzene (20 c.c.) was refluxed for 1½ hr. with sodium (0·2 g.) in methanol (10 c.c.). Recrystallisation of the precipitate (1·7 g.; m. p. 194—195°) from acetone gave the pure *methoxy-compound*, m. p. 200°, as pale yellow, opaque, flat blades (Found: C, 52·8; H, 3·35; N, 19·4. $C_9H_7O_3N_3$ requires C, 52·7; H, 3·4; N, 20·4%), $\lambda_{max.}$ 2070, 2600, and 3100 (ε 51,700, 38,800, and 6540 respectively).

4-*Methylaminocinnoline.*—4-Hydroxycinnoline (3 g.) was refluxed with phosphorus oxychloride for 30 min. and then the mixture was poured on ice (400 g.) and sodium acetate (25 g.). The chloro-compound was extracted with ether and the washed and dried extract was concentrated to *ca.* 10 c.c. before being added to phenol (30 g.) at 80°. This mixture was heated to 140° and a stream of dry methylamine passed through it for 40 min. before cooling and dilution with ether to precipitate the crude base. Pure 4-*methylaminocinnoline*, m. p. 229° (2·1 g.), was obtained by reprecipitation with sodium hydroxide solution from a solution (carbon) in acetic acid and recrystallisation (colourless needles) from water (Found: C, 66·7; H, 6·1; N, 26·4. $C_9H_9N_3,\frac{1}{4}H_2O$ requires C, 66·1; H, 5·8; N, 25·7%). The *hydrochloride*, m. p. 282°, separated from ethanol as colourless needles (Found: C, 54·1; H, 5·45; N, 21·35; Cl, 18·3. $C_9H_{10}N_3Cl$ requires C, 55·2; H, 5·15; N, 21·5; Cl, 18·1%).

4-*Methylamino*-6-*nitrocinnoline.*—An intimate mixture of 4-chloro-6-nitrocinnoline (5 g.) and phenol (50 g.) was treated with a brisk stream of dry methylamine. After a spontaneous rise in temperature to 90°, orange needles separated from the clear red solution and the passage of methylamine was continued for ½ hr. The cold mixture was diluted with ether and filtered, and the solid (5·7 g.; m. p. 260°) washed free from phenol with ether. The pure *base*, m. p. 345° (decomp.) (4 g.), was obtained by reprecipitation with ammonia from a solution (carbon) in

warm 30% acetic acid (150 c.c.); recrystallisation from *iso*propyl alcohol gave yellow needles (Found: C, 52·8; H, 4·0; N, 24·5. $C_9H_8O_2N_4$ requires C, 52·9; H, 3·95; N, 27·5%).

Reduction of Cinnoline Methiodide.—(*a*) A mixture of the salt (0·5 g.), sodium carbonate (0·1 g.), platinum oxide, and ethanol (50 c.c.) was agitated for 6½ hr. at 100° in a "Baskerville" autoclave with hydrogen (100 atm.). Basic gases (detected on release of the pressure) were passed into acid, and the filtered reaction mixture was distilled into the same acid. Titration with standard alkali indicated a 45% recovery of ammonia; ammonium picrate, m. p. and mixed m. p. 266—269° (decomp.), was isolated from half of the titration liquor whilst a determination for methylamine (as above) showed this to be absent.

(*b*) A solution of the salt (2·4 g.) in ethanol (70 c.c.) was hydrogenated at room temperature and atmospheric pressure in the presence of anhydrous sodium acetate (0·55 g.) and Raney nickel for 24 hr.; the rate of the uptake of hydrogen was negligible (170·5 c.c. used; 1 mol. = 224 c.c.). The mixture was filtered, then evaporated to dryness, and a benzene-soluble oil ("A," 1·4 g.) was separated from the residue of sodium iodide. Distillation of "A" (0·7 g.) gave a green liquid, b. p. 190°/1·5 mm., which immediately became black in air and from it no solid derivative could be prepared.

A solution of "A" (0·7 g.) in ethanol (30 c.c.) was refluxed and treated with small pieces of sodium to maintain a steady evolution of hydrogen during 1 hr. The escaping gases contained only ammonia (70% yield based upon the methiodide). The mixture was evaporated to dryness under nitrgoen, and the residue was dissolved in 1 : 1 benzene–light petroleum (b. p. 60—80°) and chromatographed (alumina; Merck–Brockmann) on a column (18 × 1 cm.). One fraction gave a red crystalline picrate, m. p. 150° (1-methylindole picrate has m. p. 150°).

Attempted Quaternisation of 4-Acetamido-8-nitrocinnoline.—The base (0·14 g.) was refluxed with methyl iodide (1·4 c.c.) in ethanol (5 c.c.) for 3½ hr. and the crystalline precipitate (0·095 g., *i.e.*, 70% recovery) of unchanged material, m. p. and mixed m. p. 290—291°, collected from the cold mixture. An identical experiment gave a 75% recovery of unchanged material and when sufficient ethanol (20 c.c.) to give complete solution was used the product was an intractable red tar.

Reduction of α- and β-4-Amino-6-nitrocinnoline Methiodide.—A solution of the α-salt (0·3 g.) in water (10 c.c.) was treated with one of stannous chloride (0·7 g. of dihydrate) in water (2 c.c.) and concentrated hydrochloric acid (3 c.c.), and the solution heated at 85°. The separation of fine needles which began after 15 min. was complete in 15 min.; the precipitate was collected from the cold mixture and digested with boiling water, then filtered, and the filtrate evaporated to dryness in a desiccator. The resulting solid (0·19 g.; m. p. 298—300°) was identical (mixed m. p.) with 4 : 6-diaminocinnoline methochloride and yielded the pure compound, m. p. 306—310°, on recrystallisation from water.

Formation of Methochlorides from "Anhydro-bases."—The anhydro-base was warmed gently with dilute hydrochloric acid until a clear solution was obtained. This solution was evaporated to dryness in a desiccator, the residue recrystallised from water, and the crystalline product compared with the corresponding authentic quaternary salt by mixed m. p. determination and by paper chromatography.

Aqueous Decomposition of 4-Amino-8-nitrocinnoline and the Derived Methiodide.—An aqueous solution of the compound (*ca.* 0·2 g. in 10 c.c.) was refluxed in a micro-Kjeldahl apparatus from which the acid traps were removed from time to time for titration against standard alkali. The following results show the relative rates of decomposition:

Time (hr.)	1	4	7	10	14	27
NH_3 (%) evolved from salt	—	1·8	—	3·4	—	9·4
" " base	10	25	65	—	80	—

Quaternisation of 4-Amino-8-nitrocinnoline.—After treatment of the base with methyl iodide in ethanol as usual, a sample of the mixture was examined by paper chromatography. Apart from spots which corresponded to the base and 4-hydroxy-8-nitrocinnoline only one spot was obtained and this showed no tendency to "tail" on prolonged running (confirmed in four experiments).

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Amides of Vegetable Origin. Part VII. Synthesis of* N-iso*Butyldodeca*-trans-2 : trans-4 : trans-8- *and* trans-2 : trans-4 : cis-8-*trienamide and Their Relation to Sanshoöl I.*

By L. Crombie and J. D. Shah.

[Reprint Order No. 6545.]

Consideration of the light absorption of sanshoöl I, the accepted gross structure of which is *N-iso*butyldodeca-2 : 4 : 8-trienamide (I), suggests that if the structure is correct, it must have a *trans*-2 : *trans*-4-configuration. The two possible stereoisomers, *trans*-2 : *trans*-4 : *trans*-8- and *trans*-2 : *trans*-4 : *cis*-8- are stereospecifically synthesised. Neither is identical with sanshoöl I. There are other discrepancies in the published spectroscopic data for sanshoöl I and it is concluded that either structure (I) is incorrect or else the amide has never been obtained in a state approaching purity. Synthesis of other stereoisomers has therefore been suspended.

The fruits of the Japanese tree *Zanthoxylum piperitum* D.C. are used as an anthelmintic and contain an insecticidal sialogogue sanshoöl I. This, on hydrogenation, yields *N-iso*butyldodecanamide (Murayama and Shinozaki, *J. Pharm. Soc. Japan*, **1931**, **51**, **379**; Asano and Kanematsu, *ibid.*, p. **384**; Asano and Aihara, *ibid.*, 1949, **69**, 79). Fresh bark is a better source of sanshoöl I and in addition is a good source of the less pungent component sanshoöl II (Aihara, *ibid.*, **1950**, **70**, 43). Sanshoöl I is very unstable to air, absorbs hydrogen equivalent to 3·24 double bonds over a palladium catalyst, and on oxidation with permanganate yields *N-iso*butyloxamic, succinic, oxalic, and butyric acid. Its ultraviolet-light absorption ($\lambda_{max.}$ 267·5 mμ, ε 33,000) indicates, according to Aihara (*loc. cit.*), the presence of a conjugated dienamide chromophore, and on this basis he considers sanshoöl I to be *N-iso*butyldodeca-2 : 4 : 8-trienamide (I).

$$CH_3\cdot[CH_2]_4\cdot CH{:}CH\cdot[CH_2]_4\cdot CH{:}CH\cdot CH{:}CH\cdot CO\cdot NHBu^i \quad (I)$$

This paper reports limited syntheses in this field. There are eight possible stereoisomers of the triene (I) but if the gross structure proposed by Aihara is correct, and his preparation is uncontaminated by impurity having strong light absorption in the 267·5 mμ region, only those isomers with a *trans*-2 : *trans*-4-diene system can be entertained. This follows from the extinction coefficient since absorption data for the four stereoisomeric *N-iso*butyldeca-2 : 4-dienamides (Part V, Crombie, *J.*, 1955, 1007) suggest that any *cis*-containing combination of linkages in the 2 : 4-diene system of sanshoöl I would give rise to a value of less than ~26,000. Confirmatory information might come from infrared absorption measurements or ease of reaction with maleic anhydride but these have not been reported for the natural product. Accepting this simplifying evidence, we have now prepared the two stereoisomers with *trans*-2 : *trans*-4-linkages.

Table 1. *Dodeca*-2 : 4 : 8-*trienoic acids.*

	M. p.	*p*-Bromophenacyl ester, m. p.	*N-iso*Butylamide, m. p.	Unsatn.[a]
all-*trans*	80—81°	128°	97—98°	2·8
trans-2 : *trans*-4-*cis*-8	23—23·5	87—87·5	62—63	3·1

[a] No. of double bonds determined by microhydrogenation of the *iso*butylamide.

All-*trans*-(I) was synthesised by application of the coupling reaction reported in Part II (Crombie, *J.*, 1952, 4388) which gives the crude enyne hydrocarbon (II). By a series of steps, applied previously in a similar case (Crombie, *Chem. and Ind.*, 1952, 1034; Part V, *loc. cit.*), this was converted into the crystalline *trans*-2 : *trans*-4 : *trans*-8-acid (IV) and its *iso*butylamide. Properties of these compounds are summarised in Table 1.

The *trans*-2 : *trans*-4 : *cis*-8-amide (I) was built up from nona-1 : 5-diyne, prepared by

* Part VI, *J.*, 1955, 1025.

Raphael and Sondheimer's method (*J.*, 1950, 120). This was converted into 1 : 1-diethoxydeca-2 : 6-diyne and thence, by semi-hydrogenation, into the *cis-cis*-diene acetal whence acidic hydrolysis produced the *trans*-2 : *cis*-6-diene aldehyde (III), inversion of

$$Pr^n\cdot CH{=}CH\cdot CH_2Br + Br\cdot Mg\cdot CH_2\cdot C{\equiv}CH \longrightarrow Pr^n\cdot CH{=}CH\cdot CH_2\cdot CH_2\cdot C{\equiv}CH \quad (II)$$

$$\xrightarrow[CH(OEt)_3]{R\cdot MgX-} Pr^n\cdot CH{=}CH\cdot CH_2\cdot CH_2\cdot C{\equiv}C\cdot CH(OEt)_2 \xrightarrow[H^+]{Pd\text{-}H} Pr^n\cdot CH{=}CH\cdot CH_2\cdot CH_2\cdot CH{=}CH\cdot CHO \quad (III)$$

$$\xrightarrow{Doebner} Pr^n\cdot CH{=}CH\cdot CH_2\cdot CH_2\cdot CH{=}CH\cdot CH{=}CH\cdot CO_2H \longrightarrow \text{all-}trans\text{-} \quad (I)$$
(IV)

configuration occurring only at the 2 : 3-position (for references see Part V); Raphael and Sondheimer (*J.*, 1951, 2693) used this reaction in a similar case. Properties of the two stereoisomeric deca-2 : 6-dienals prepared in this investigation are summarised in Table 2. The aldehydes have extremely persistent odours, detectable at high dilution, in line with their being higher homologues of the perfume, violet leaf aldehyde, nona-2 : 6-dienal (Sondheimer, *J. Amer. Chem. Soc.*, 1952, **74**, 4040). The 2 : 4-dinitrophenylhydrazone of the *cis-trans*-aldehyde was obtained in two forms, which had identical melting points, ultraviolet light absorptions, and infrared spectra (paraffin mulls), and there is no doubt that they are polymorphs and not geometrical isomers about the C=N linkage as has sometimes been found (cf. Ramirez and Kirby, *ibid.*, 1954, **76**, 1037).

TABLE 2. *Deca-2 : 6-dienals.*

				2 : 4-Dinitrophenylhydrazone			
2 : 3	6 : 7	$\lambda_{max.}$ (mμ) [a]	ε		M. p.	$\lambda_{max.}$ [b]	ε
trans	*trans*	217	12,500	Flat, orange needles	125·5°	375	30,000
cis	*trans*	217	13,500	Red-orange needles	115—116	375	27,000
				Yellow plates	115—116	374	26,500

[a] In hexane. [b] In chloroform.

In an alternative approach to the *trans-cis*-series, coupling of hex-*cis*-2-enyl chloride and propargylmagnesium bromide gave the crude hydrocarbon (II), and among other contaminants allenic material was present. Conversion into the decadienal was carried out as in the *trans-trans*-series. The product was shown to have the *trans*-2 : *cis*-6-configuration by conversion into the 2 : 4-dinitrophenylhydrazone and comparison with the specimens obtained as above. Configuration of the *cis*-halide involved in the coupling must therefore be largely retained. This, and related reactions of geometrically isomeric allylic compounds, will be discussed elsewhere.

Infrared spectra of the two stereoisomeric deca-2 : 4 : 8-trienoic acids and amides have been examined and relevant data are in Table 3. The *trans*-2 : *trans*-4 : *trans*-8-trienamide

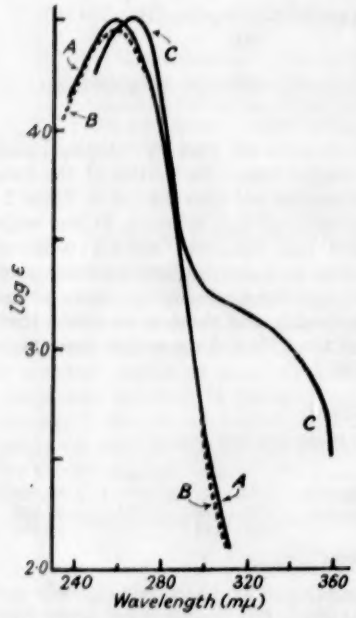
TABLE 3. *Infrared assignments (cm.$^{-1}$) for dodecatrienoic acids and amides.*[a]

2 : 3	4 : 5	8 : 9	NH		C=O	$C{=}C_I$	$C{=}C_{II}$	ΔC=C	δ'(CH=CH)$_2$
					*iso*Butylamides [b]				
trans	*trans*	*trans*	3265	3060	1623	1655	1613	42	993	967
trans	*trans*	*cis*	3295	3060	1626	1657	1618	39	998	—
					Acid				
trans	*trans*	*trans*	—	—	1684	1634	1610	24	1005	968
trans	*trans*	*cis*	—	—	1684	1636	1613	23	1000	—

[a] Paraffin mulls. [b] See Part V, Table 9, for comparative data.

is particularly interesting. From our previous data (Part V) we would expect one strong band in the out-of-plane deformation region to be present at 994 cm.$^{-1}$ because of the *trans*-2 : *trans*-4-diene system, and one at *ca.* 968 cm.$^{-1}$ because of the internal *trans*-linkage. Both are present. However, had the stereochemistry of this compound not been known from stereospecific synthesis, the two vibrations might alternatively have been ascribed

to a *cis*-2 : *trans*-4- or *trans*-2 : *cis*-4-diene*iso*butylamide system since two vibrations, at approximately 995 and 962 cm.$^{-1}$, are characteristic of this (Part V). The example emphasises the need for care in application of infrared correlations in complex molecules. As expected, only one strong band at 998 cm.$^{-1}$ is found for a *trans*-2 : *trans*-4 : *cis*-8-compound in the region under consideration. Both stereoisomeric amides have C=C stretching vibrations in the position expected for a *trans*-2 : *trans*-4-diene.



Absorption spectra of (*A*) N-iso*butyldeca*-trans-2 : trans-4 : trans-8-*trienamide*, (*B*) *its* trans-2 : trans-4 : cis-8-*isomer*, *and* (*C*) *sanshoöl* I (*Aihara's curve*).

*N-iso*Butyldodeca-*trans*-2 : *trans*-4 : *cis*-8-trienamide is physiologically more active than the all-*trans*-isomer. It is a more potent sialogogue and has knock-down and low toxicity towards *Tenebrio molitor* (the first completely synthetic *iso*butylamide to show significant toxicity towards this insect) : the all-*trans*-compound is almost inactive in these respects. When tested against houseflies the *trans*-2 : *trans*-4 : *cis*-8- was markedly more effective than the all *trans*-isomer but only about half as effective as *N-iso*butyldeca-*trans*-2 : *trans*-4-dienamide. [Testing of the four stereoisomers of the latter structure (Part V) has now been completed against houseflies. Like the *trans*-2 : *cis*-4-, the *cis*-2 : *trans*-4- and the *cis*-2 : *cis*-4-diene*iso*butylamides are only about one-tenth as toxic as the *trans*-2 : *trans*-4-compound, stressing the dependence of physiological activity on stereochemistry in these compounds.]

The melting points of both *N-iso*butyldeca-2 : 4 : 8-trienamides and the lack of physiological effects from the all-*trans*-isomer make it impossible to equate either of them with natural sanshoöl I which, according to Aihara, is an oil, difficult to crystallise from any solvent, though solidifying at room temperature. Either sanshoöl I is not (I) or else the natural stereoisomer of gross structure (I) has not yet been isolated pure. The position of its maximal absorption is at appreciably longer wavelengths than is usual for a conjugated dienamide (see Figure and Table 4) and Aihara's curve has a strong inflexion at long wavelength which is inexplicable for a compound of gross structure (I).

In the light of these results we have postponed further synthetic work on stereoisomers of the amide (I) until natural sanshoöl I has been re-examined.

TABLE 4. *Ultraviolet-light absorption data for decadienoic and dodecatrienoic acid derivatives (in absolute ethanol).*

2 : 3	4 : 5	8 : 9		Acid	*N-iso*Butylamide	*p*-Bromophenacyl ester
trans	*trans*	*trans*	$\lambda_{max.}$	259	259	264
			ε	27,000	32,000	48,500
trans	*trans*	*cis*	$\lambda_{max.}$	259	259	264
			ε	25,500	29,000	49,000
trans	*trans* [a]	—	$\lambda_{max.}$	257	258	263
			ε	28,500	29,500	52,000

[a] See Part V for data on the remaining three stereoisomers.

EXPERIMENTAL

Analyses and light-absorption measurements were carried out in the microanalytical (Mr. F. H. Oliver) and spectrographic (Mrs. I. Boston and Mr. R. L. Erskine, B.Sc.) laboratories of this Department. The ultraviolet absorptions were determined with a Unicam instrument

unless otherwise stated (I.B.) and the infrared absorptions with a Grubb-Parsons double beam instrument (R.L.E.). For further data see Tables.

1 : 1-*Diethoxydeca*-trans-6-*en*-2-*yne*.—Crude nona-*trans*-5-en-1-yne was prepared by treating propargylmagnesium bromide (from propargyl bromide, 46·0 g., and magnesium, 9·2 g.) in anhydrous ether (120 ml.) with *trans*-hex-2-enyl bromide (57·0 g.) [Bouis, *Ann. Chim.* (*France*), 1928, **9**, 403] in ether (60 ml.). For details see Crombie (Part II). The crude product had b. p. 144—155° (22·5 g.), n_D^{21} 1·4520—1·4525, and was contaminated with halogen-containing impurity.

Crude nona-5-en-1-yne (22·5 g.) in dry ether (50 ml.) was added to a Grignard reagent prepared from magnesium (4·88 g.) and ethyl bromide (26 g.) in ether (100 ml.). The product was heated under reflux (2 hr.), then cooled, and ethyl orthoformate (35 g.) was added dropwise. After further heating under reflux (6 hr.) the ether was evaporated and the residue maintained at 100° (1 hr.), cooled, and treated with ether and saturated ammonium chloride solution. The organic layer was isolated with ether, washed with saturated ammonium chloride solution, then water, and dried ($MgSO_4$). Solvent and excess of ethyl orthoformate were evaporated and the residue, when distilled, gave 1 : 1-*diethoxydeca*-trans-6-*en*-2-*yne* (10·7 g.), b. p. 86°/0·5 mm., n_D^{20} 1·4520 (Found : C, 74·35; H, 10·95. $C_{14}H_{24}O_2$ requires C, 74·9; H, 10·8%).

1 : 1-*Diethoxydeca*-cis-2 : trans-6-*diene*.—The above enyne (10·24 g.) was mixed with ethyl acetate (50 ml.) and added to pre-hydrogenated Lindlar catalyst (2·0 g.) in ethyl acetate (50 ml.). This mixture was shaken in hydrogen until 965 ml./N.T.P. had been absorbed (calc. for absorption of 1 mol., 1025 ml./N.T.P.). As the hydrogenation became slow, fresh catalyst (6·0 g.) was added after 780 ml. of gas had been absorbed. Filtration, evaporation, and distillation gave 1 : 1-*diethoxydeca*-cis-2 : trans-6-*diene* (8·6 g.), b. p. 78—80°/0·8 mm., n_D^{19} 1·4509 (Found : C, 74·7; H, 11·45. $C_{14}H_{26}O_2$ requires C, 74·35; H, 11·6%).

Deca-trans-2 : trans-6-*dienal*.—1 : 1-Diethoxydeca-*cis*-2 : *trans*-6-diene (9·2 g.) was rapidly steam-distilled from 2N-sulphuric acid (150 ml.). The distillate (350 ml.) was saturated with salt and throughly extracted with ether. The extracts were dried and evaporated and the trans-2 : trans-6-*diene aldehyde* (5·2 g.) distilled; it had b. p. 72—74°/0·1 mm., n_D^{20} 1·4678 (Found : C, 79·1; H, 10·8. $C_{10}H_{16}O$ requires C, 78·9; H, 10·6%). The 2 : 4-*dinitrophenylhydrazone* crystallised from 95% ethanol in flat orange needles. It melted completely at 125·5° after sudden shrinkage to a turbid liquid at 124° (Found : C, 57·7; H, 6·0; N, 16·9. $C_{16}H_{20}O_4N_4$ requires C, 57·8; H, 6·0; N, 16·8%).

Dodeca-trans-2 : trans-4 : trans-8-*trienoic Acid*.—Deca-*trans*-2 : *trans*-6-dienal (5·2 g.) was added to an ice-cold mixture of malonic acid (4·27 g.) and anhydrous pyridine (4 ml.) and set aside at 25° (48 hr.). Two phases which were formed initially disappeared by the end of this time. The product was heated at 110° (1 hr.), cooled, and acidified with ice-cold 50% sulphuric acid, and the acidic and neutral materials were extracted with light petroleum (b. p. 40—60°). The *acid* was extracted from this with 10% sodium hydroxide solution and purified in the usual way. On distillation it had b. p. 140—150°/0·05 mm. (2·34 g.) and crystallised. After one crystallisation from light petroleum (b. p. 40—60) it had m. p. 70—73° raised after three crystallisations to m. p. 80—81° (shining plates) (Found : C, 73·95; H, 9·5. $C_{12}H_{18}O_2$ requires C, 74·2; H, 9·35%). The p-*bromophenacyl ester* formed flat needles from ethanol (Found : Br, 20·5. $C_{20}H_{23}O_3Br$ requires Br, 20·45%).

N-iso*Butyldodeca*-trans-2 : trans-4 : trans-8-*trienamide*.—The foregoing acid (0·21 g.) was treated with a slight excess of thionyl chloride and set aside overnight. After being heated under reflux for 20 min. the product was distilled and the acid chloride collected (b. p. 110—120°/0·25 mm.), treated in anhydrous ether with excess of ethereal *iso*butylamine, and poured into water. The mixture was extracted with ether, and the extract washed with N-sodium hydroxide, N-hydrochloric acid, and water. After drying and evaporation the *product* crystallised from light petroleum (b. p. 40—60°) as needles (150 mg.) (Found : C, 76·7; H, 10·65. $C_{16}H_{27}ON$ requires C, 77·05; H, 10·9%).

1-*Chlorohex*-cis-2-*ene*.—Pent-1-ynylmagnesium bromide was prepared from pent-1-yne (40·8 g.) in ether in the usual way and converted into hex-2-yn-1-ol (38 g., 65%; b. p. 100°/53 mm., n_D^{17} 1·4540) by treatment with gaseous formaldehyde according to the method of Newman and Wotiz (*J. Amer. Chem. Soc.*, 1949, **71**, 1292). The 3 : 5-dinitrobenzoate had m. p. 67° (Newman and Wotiz give b. p. 87—89°/58 mm.; 3 : 5-dinitrobenzoate, m. p. 64—65°).

Hex-2-yn-1-ol (40·0 g.) was hydrogenated in ethyl acetate (50 ml.) with a pre-reduced palladium–calcium carbonate catalyst (5%; 3 g.) until 9·14 l. of hydrogen had been absorbed at N.T.P. The catalyst was removed, solvent evaporated, and the residue distilled, giving *cis*-hex-2-en-1-ol (28·8 g.), b. p. 90—91°/56 mm., n_D^{23} 1·4363. This alcohol (280 g.) in pyridine

(8·0 g.) was treated at −10° to −15° with phosphorus trichloride (18 g.) with vigorous stirring, then stirred for 1 hr. at −10° and 1 hr. at 25°. The crude chloride (33 g.) was isolated by distillation at 0·05 mm. When washed with sodium hydrogen carbonate solution and then with water and distilled, the *chloride* (17·3 g.) had $n_D^{19\cdot5}$ 1·4430 (Found: C, 61·5; H, 9·65. $C_6H_{11}Cl$ requires C, 60·75; H, 9·3%). It showed only weak absorption at ~966 cm.$^{-1}$.

Preparation of 1 : 1-*Diethoxydeca*-cis-6-*en*-2-*yne by the Coupling Method.*—The coupling was carried out with propargyl bromide (18·5 g.), magnesium (3·74 g.), and 1-chlorohex-*cis*-2-ene (17·3 g.) under conditions similar to those described in Part II. Crude hydrocarbon (21·9 g.), b. p. 130—140°, n_D^{21} 1·4650—1·4700, was collected by distillation. Halogen was present and the infrared spectrum showed the presence of allene (1963 cm.$^{-1}$) as well as monosubstituted acetylene (3250, 2135 cm.$^{-1}$).

Crude hydrocarbon (21·9 g.) in ether (30 ml.) was added to ethylmagnesium bromide (from magnesium, 4·5 g.) in ether (150 ml.), stirred for 1 hr. at 25°, and then refluxed for 1 hr. Ethyl orthoformate (25 g.) was added after cooling and the mixture refluxed for 6 hr. in nitrogen. The ether was removed by distillation, the residue heated for 1 hr. on the steam-bath, and cold saturated ammonium chloride added. Extraction with ether, washing, drying, and distillation gave 1 : 1-*diethoxydec*-cis-6-*en*-2-*yne* (2·0 g.), b. p. 104°/0·5 mm., $n_D^{20\cdot5}$ 1·4581 (Found: C, 74·7; H, 10·8. $C_{14}H_{24}O_2$ requires C, 74·95; H, 10·8%).

Deca-trans-2 : cis-6-*dienal.*—The enyne acetal (1·91 g.) was hydrogenated in purified light petroleum (20 ml.; b. p. 80—100°) with pre-hydrogenated Lindlar catalyst (1·2 g.). Gas absorption ceased when 180 ml. of hydrogen at N.T.P. had been absorbed (calc. for semi-reduction of the acetylenic linkage, 198 ml. at N.T.P.). Filtration, evaporation, and distillation gave 1 : 1-diethoxy-*cis*-2 : *cis*-6-diene, b. p. 80°/0·5 mm., $n_D^{22\cdot5}$ 1·4470.

The acetal (0·5 g.) was steam-distilled from 2N-sulphuric acid, and the distillate (25 ml.) saturated with salt, and thoroughly extracted with ether. Drying, evaporation, and distillation gave the trans-2 : cis-6-*diene aldehyde*, b. p. 59—60°/0·1 mm., $n_D^{21\cdot5}$ 1·4730 (Found: C, 78·95; H, 10·6. $C_{10}H_{16}O$ requires C, 78·9; H, 10·6%). Its 2 : 4-dinitrophenylhydrazone had m. p. 114—115°, undepressed (114—116°) when admixed with the 2 : 4-dinitrophenylhydrazone of deca-*trans*-2 : *cis*-6-dienal prepared by the stereospecific method described below.

Nona-1 : 5-*diyne.*—Hexa-1 : 5-diene, prepared by Turk and Channan's method (*Org. Synth.*, 1949, **27**, 7), was converted into the tetrabromide in 92% yield. The latter (620 g.) was dehydrobrominated according to Raphael and Sondheimer's directions (*J.*, 1950, 120) with sodamide from sodium (310 g.) and ferric nitrate (3 g.) in liquid ammonia (5 l.), to give hexa-1 : 5-diyne (54 g.; 47%), b. p. 89—90°, $n_D^{27\cdot5}$ 1·4342. Monoalkylation according to the same authors' directions gave nona-1 : 5-diyne (54·3 g., 45%), b. p. 80°/10—12 mm., $n_D^{19\cdot5}$ 1·4560, from hexa-1 : 5-diyne (78 g.) and propyl iodide (180 g.). Raphael and Sondheimer (*loc. cit.*) give b. p. 87·5—88·5°/758 mm., n_D^{23} 1·4380—1·4382, for hexa-1 : 5-diyne and b. p. 62°/19 mm., n_D^{21} 1·4562—1·4565, for nona-1 : 5-diyne.

1 : 1-*Diethoxydeca*-2 : 6-*diyne.*—Nona-1 : 5-diyne (54·3 g.) in ether (100 ml.) was added to ethylmagnesium bromide, prepared from magnesium (11·95 g.) and ethyl bromide (60 g.) in ether (160 ml.), and heated under reflux for 2 hr. Ethyl orthoformate (80 g.) was added and refluxing continued for 6 hr. The ether was then distilled, the residue heated on a steam-bath for 1 hr., then cooled, and saturated ammonium chloride solution and ether were added. Washing, drying, and distillation of the organic layer gave 1 : 1-*diethoxydeca*-2 : 6-*diyne* (68 g.), b. p. 96—98°/0·15 mm., 108°/0·35 mm., n_D^{19} 1·4599 (Found: C, 75·7; H, 10·1. $C_{14}H_{22}O_2$ requires C, 75·65; H, 9·95%).

Deca-trans-2 : cis-6-*dienal.*—The diyne acetal (14·9 g.) was hydrogenated in ethyl acetate (40 ml.) and quinoline (1 ml.) containing Lindlar catalyst (8 g.). When 3·01 l. (N.T.P.) of hydrogen had been absorbed, reaction was stopped (gas absorption had almost ceased) and the mixture filtered. The filtrate was washed with 2N-hydrochloric acid to remove quinoline, then with water, and dried. On evaporation of the solvent the strong aldehyde odour suggested that some hydrolysis had taken place. 1 : 1-Diethoxydec-*cis*-2 : *cis*-6-diene was therefore not purified but the crude acetal was steam-distilled from 2N-sulphuric acid (110 ml.). In a second experiment in which neither quinoline nor acid treatment was employed, 1 : 1-*diethoxydeca*-cis-2 : cis-6-*diene* (70%), b. p. 86°/0·35 mm., n_D^{22} 1·4485, was isolated (Found: C, 74·45; H, 11·5%). The steam-distillate was saturated with salt and extracted with ether. These extracts were dried, evaporated, and distilled, to give deca-*trans*-2 : *cis*-6-dienal (7·5 g.), b. p. 58—60°/0·2 mm. (Found: C, 78·9; H, 10·7%). The 2 : 4-*dinitrophenylhydrazone* (Found: C, 57·7; H, 6·0%) was obtained as red-orange needles by slow crystallisation from ethanol. Yellow plates with marked electrostatic properties separated from the filtrate and also when the needle form was

dissolved and crystallised from hot ethanol. Both forms had m. p. 115—116° and this was not depressed on admixture. When admixed with the 2 : 4-dinitrophenylhydrazone of the *trans-trans*-aldehyde there was a marked depression of m. p.

Dodeca-trans-2 : trans-4 : cis-8-*trienoic Acid*.—The *trans*-2 : *cis*-4-aldehyde (7·3 g.) was added with shaking to finely powdered malonic acid (5·9 g.) in anhydrous pyridine (4·5 ml.) at 0° and set aside for 48 hr. at 25°. The mixture was then worked up as described for the all-*trans*-acid and distilled, to give crude *acid* (3·6 g.), b. p. 135—148°/0·07 mm., n_D^{20} 1·5110—1·5210. It was purified by crystallisation at −5° from light petroleum (b. p. 40—60°) and then had m. p. 23—23·5° (needles) (Found : C, 74·3; H, 9·5%). Its p-*bromophenacyl ester* formed plates from a small volume of 95% ethanol (Found : C, 61·3; H, 6·2. $C_{20}H_{23}O_3Br$ requires C, 61·3; H, 6·0%).

N-iso*Butyldodeca*-trans-2 : trans-4 : cis-8-*trienamide*.—This *amide* was prepared in a similar manner to the all-*trans*-amide and crystallised at low temperature from light petroleum (b. p. 60—80°) (Found : C, 76·85; H, 10·85%).

Hydrogenation of the Triene Acids.—The all-*trans*- and the *trans*-2 : *trans*-4 : *cis*-8-acid were completely hydrogenated in acetic acid. After filtration, the solvent was evaporated. Without further purification the residues melted at 44·5° and 45° respectively and were not depressed on admixture with genuine lauric acid.

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Rearrangement in the Demethylation of 2′-Methoxyflavones. Part II. Further Experiments and the Determination of the Composition of Lotoflavin.*

By M. L. Doporto, (Miss) K. M. Gallagher, J. E. Gowan, (Miss) A. C. Hughes, (Mrs.) E. M. Philbin, T. Swain, and T. S. Wheeler.

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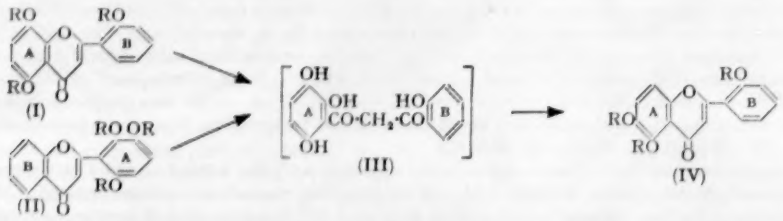
Both 5 : 8 : 2′-trimethoxyflavone (I; R = Me) and the 2′ : 3′ : 6′-isomer (II; R = Me) yield 5 : 6 : 2′-trihydroxyflavone (IV; R = H) on demethylation by hydriodic acid. This result confirms previous views (see Gallagher *et al.*, *J.*, 1953, 3770) that the diketone produced by decyclisation, *e.g.*, (III), is intermediate in the rearrangement of both 5 : 8-dihydroxy- and 2′-hydroxyflavones. The presence of hydrogen ion is necessary for the 5 : 8 ⟶ 5 : 6 rearrangement of flavones.

Experiments related to the structure of lotoflavin, which Dunstan and Henry (*Phil. Trans.*, 1901, **194**, *B*, 515) thought to be 5 : 7 : 2′ : 4′-tetrahydroxyflavone (V; R = H) have shown that 7 : 2′ : 4′ : 6′-tetramethoxyflavone (VI; R = Me) rearranges to form (V; R = H) on treatment with hydriodic acid. Lotoflavin as represented by the samples available is now found to be quercetin containing some kæmpferol.

Gallagher, Hughes, O'Donnell, Philbin, and Wheeler (Part I *) found that certain 2′-methoxyflavones are rearranged during demethylation by hydriodic acid under sufficiently drastic conditions to give the related 2′-hydroxyflavones in which the 2-phenyl group and the fused aromatic ring of the original flavone are interchanged (compare I and IV with II). Their suggestion that an intermediate disalicyloylmethane of the type (III) occurs in the rearrangement has been confirmed; both 5 : 8 : 2′-trimethoxyflavone (I; R = Me) and the 2′ : 3′ : 6′-isomer (II; R = Me) give 5 : 6 : 2′-trihydroxyflavone (IV; R = H) on treatment with hydriodic acid. Cyclisation of the diketone (III) can occur in three ways to form

* Part I, *J.*, 1953, 3770.

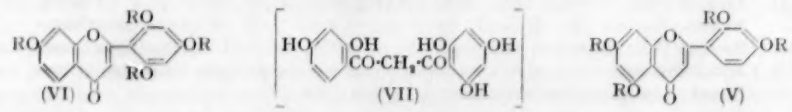
(I; R = H), (II; R = H) or (IV; R = H). As shown by Gallagher *et al.* (*loc. cit.*) the more stable of two related 2′-hydroxyflavones, *e.g.*, (II and IV; R = H), is that in which the 2-phenyl side chain contains the smaller number of hydroxyl groups. The greater stability of a 5 : 6-dihydroxyflavone, *e.g.*, (IV; R = H), than of a 5 : 8-dihydroxyflavone, *e.g.*, (I; R = H), is well known.



Demethylation Experiments.—Gallagher *et al.* (*loc. cit.*) also suggested that the 5 : 8 ⟶ 5 : 6 (I ⟶ IV) and the 2′-rearrangement (II ⟶ IV) involve the formation of a hydrogen bond between the hydroxyl-oxygen atom at positions 8 or 2′, and the oxide-oxygen atom at position 1. Support is afforded to this view as regards the (I ⟶ IV) change by the results of some experiments (Table 1) on the demethylation of 5 : 8-dimethoxyflavone by various reagents. The presence of hydrogen ion is found to be necessary to produce rearrangement of 5 : 8- to 5 : 6-dihydroxyflavone. Experiments on the yields obtained in the demethylation of 7-methoxyflavone by various reagents are also included.

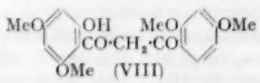
Composition of Lotoflavin

5 : 7 : 2′ : 4′- *and* 7 : 2′ : 4′ : 6′-*Tetrahydroxyflavone.*—Dunstan and Henry (*Phil. Trans.*, 1901, **194**, *B*, 515; Henry, *J. Soc. Chem. Ind.*, 1938, **57**, 248) claimed that a flavone which they had isolated from *Lotus arabicus*, and which they called "Lotoflavin," was 5 : 7 : 2′ : 4′-tetrahydroxyflavone (V; R = H). Synthesis of this tetrahydroxyflavone by Cullinane, Algar, and Ryan (*Sci. Proc. Roy. Dublin Soc.*, 1928, **19**, 77; cf. Gupta and Seshadri, *Proc. Indian Acad. Sci.*, 1953, **37**, *A*, 611) and by Robinson and Venkataraman (*J.*, 1929, 61) showed that it has not the properties of lotoflavin. Since both methods of synthesis involve demethylation by hydriodic acid in the final stage, it seemed possible that the product (V; R = H) might have undergone the 2′-type rearrangement to the related 7 : 2′ : 4′ : 6′-tetrahydroxyflavone (VI; R = H) with intermediate formation of the diketone (VII). However, this view proved untenable for, in line with the results on stability given in Part I (*e.g.*, system IV more stable than II), it has now been confirmed that it is (VI; R = H) which rearranges to form (V; R = H) (see also Gupta and Seshadri, *loc. cit.*). Further, the pentamethyl ether (IX) cyclises with hydriodic acid to (V; R = H), and does not give (VI; R = H) as Cullinane *et al.* (*loc. cit.*) supposed.

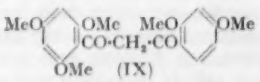


The synthesis of the ether (V; R = Me) required the cyclisation of 2 : 4-dimethoxybenzoyl-(2-hydroxy-4 : 6-dimethoxybenzoyl)methane (VIII). This diketone was obtained with m. p. 120° both by the Claisen ester-ketone condensation, and by an Allan–Robinson fusion of 2-hydroxy-4 : 6-dimethoxyacetophenone and 2 : 4-dimethoxybenzoic anhydride in presence of triethylamine (cf. Kuhn and Löw, *Ber.*, 1944, **77**, 197) followed by alkaline hydrolysis of the product. Previous workers in attempting the synthesis of the diketone (VIII) by the Claisen method obtained in fact the pentamethyl ether (IX), m. p. 151°, owing to the presence of methyl sulphate in the methyl 2 : 4-dimethoxybenzoate used in the synthesis.

The exclusion of the possibility that 5 : 7 : 2′ : 4′-tetrahydroxyflavone had rearranged to 7 : 2′ : 4′ : 6′-tetrahydroxyflavone on treatment with hydriodic acid led to a re-examination of the lotoflavin problem. The structure which Dunstan and Henry (*loc. cit.*) assigned to lotoflavin depended mainly on the result of an alkaline fusion which, these workers



(VIII)



(IX)

thought, gave β-resorcylic acid and phloroglucinol. The evidence for the occurrence of these products was weak. The identification of the acid rested chiefly on the observed m. p. (207°). The m. p. of some of the dihydroxybenzoic acids is indefinite; Beilstein records 194—217° for β-resorcylic acid and 194—205° for protocatechuic acid. Even if Dunstan and Henry's identification of the degradation products were correct, the fact remains that 5 : 7 : 2′ : 4′- and 7 : 2′ : 4′ : 6′-tetrahydroxyflavone would give the same products on alkaline fusion. However, the properties of 7 : 2′ : 4′ : 6′-tetrahydroxyflavone and of its tetra-acetate (see Experimental section) differ from those described for lotoflavin.

Scrutiny of the literature did not reveal a tetrahydroxyflavone with properties like those recorded for lotoflavin. Derivatives of 3 : 5 : 7 : 3′-tetrahydroxyflavone (Shaw and Simpson, *J.*, 1952, 5031) which gave a tetra-acetate with m. p. near that recorded for lotoflavin tetra-acetate, and of the 5 : 7 : 3′ : 5′-isomer, which is new, were synthesised, with similar negative results.

Examination of Lotoflavin Specimens.—Dr. Henry (personal communication) stated that no specimen of lotoflavin remains with him. However, a sample (35 mg.), labelled "lotoflavin," was kindly made available by Professor J. Algar. Dr. N. M. Cullinane (personal communication) states that it was supplied by Dr. Harold Brown of the Imperial Institute, where Dunstan and Henry worked. It was found to be identical with a second authentic specimen (*ca.* 5 mg.) which was obtained later through the courtesy of Sir Robert Robinson. Comparative chromatographic runs were made on paper between a number of flavones including 5 : 7 : 2′ : 4′-tetrahydroxyflavone, 5 : 7 : 4′-trihydroxyflavonol (kæmpferol), 5 : 7 : 2′ : 4′-tetrahydroxyflavonol (morin), 5 : 7 : 3′ : 4′-tetrahydroxyflavonol (quercetin), and the lotoflavin specimen.

The specimen gave two spots in all solvent systems tried, the major one of which had R_F values and colour reactions identical with those of quercetin; the second component, present only in trace amounts, had R_F values and colour reactions indistinguishable from those of kæmpferol (Table 2). The major component was strongly retarded on borate-buffered filter paper in butan-1-ol–water, showing the presence of an *o*-dihydroxy-grouping (Wachtmeister, *Acta Chem. Scand.*, 1951, **5**, 976; Swain, *Biochem. J.*, 1952, **53**, 200). The presence of this grouping was confirmed on identification by paper chromatography of protocatechuic acid together with phloroglucinol as the products of alkaline degradation of lotoflavin on a microscale (cf. Bate-Smith and Swain, *J.*, 1953, 2187). The same degradation products were given by quercetin. The ultraviolet spectra of lotoflavin in ethanol, 0·002M-sodium ethoxide (Mansfield, Swain, and Nordström, *Nature*, 1953, **172**, 23), and 0·1% ethanolic aluminium chloride (Swain, *Chem. and Ind.*, 1954, 1480) were identical with those of quercetin (Table 3), and the infrared spectra of the two compounds in the double bond (5·5—7 μ) and "finger print" regions (8—12 μ) were also indistinguishable. Further, the m. p. of acetylated lotoflavin was not depressed by the addition of quercetin penta-acetate and the ultraviolet spectra of these two derivatives in ethanol and 0·1% ethanolic aluminium chloride had identical absorption maxima. Robinson and Venkataraman (*loc. cit.*) commented on the similarity in dyeing properties of lotoflavin and quercetin.

It is clear, therefore, that lotoflavin, as represented by the two samples available, is quercetin with, probably, 1—2% (see the Experimental section for estimation of percentage) of kæmpferol. It is interesting that these two flavonols occur together in tea leaves (Oshima and Goma, *J. Agric. Chem. Soc. Japan*, 1933, **9**, 948; Oshima and Ka, *ibid.*, 1936, **12**, 975), and in strawberries (*Fragaria chiloensis*) (Williams and Wender, *J. Amer. Chem. Soc.*, 1952, **74**, 5919).

Experimental

Ethanol was employed for crystallisation if no solvent is mentioned.

5 : 8 : 2′-, 2′ : 3′ : 6′-, and 5 : 6 : 2′-Trimethoxyflavone : Preparation and Demethylation by Aluminium Chloride.—(1) *5 : 8 : 2′-Trihydroxyflavone* (I; R = H). *2-o-Anisoyloxy-3 : 6-dimethoxyacetophenone*, which was prepared from 2-hydroxy-3 : 6-dimethoxyacetophenone (Baker, Brown, and Scott, *J.*, 1939, 1924) by the pyridine–acid chloride method (see Nowlan, Slavin, and Wheeler, *J.*, 1950, 342), crystallised in plates, m. p. 90° (Found : C, 65·2; H, 5·5; OMe, 28·0. $C_{18}H_{18}O_6$ requires C, 65·5; H, 5·5; 3OMe, 28·2%). This ester was shaken in pyridine with powdered potassium hydroxide (1·5 mols.) for 3 hr. and the mixture was poured on ice and hydrochloric acid. The crude product, which separated as an oil, crystallised from methanol and gave *o-anisoyl-3 : 6-dimethoxysalicyloylmethane* in yellow plates (70% yield), m. p. 84—86° (Found : C, 65·5; H, 5·5; OMe, 27·9%. Required : as for the ester), and gave a greenish-brown colour with ethanolic ferric chloride. The hydroxy-diketone was boiled for 3 min. with glacial acetic acid containing a few drops of hydrochloric acid. Controlled addition of water precipitated *5 : 8 : 2′-trimethoxyflavone* (I; R = Me) which crystallised in plates, m. p. 200—201° (Found : C, 68·7; H, 4·9; OMe, 30·8. $C_{18}H_{16}O_5$ requires C, 69·2; H, 5·1; 3OMe, 29·8%). This flavone was refluxed ($CaCl_2$ guard) in benzene for 1 hr. with anhydrous aluminium chloride (5 pts.), and the insoluble residue was treated with ice and 10% hydrochloric acid. The mixture was heated on a steam-bath for 15 min. and cooled. *5 : 8 : 2′-Trihydroxyflavone* crystallised in pale yellow needles, m. p. *ca.* 310° (Found : C, 66·3; H, 3·9. $C_{15}H_{10}O_5$ requires C, 66·7; H, 3·7%), and gave an olive-green colour with ethanolic ferric chloride [*triacetate* (acetic anhydride–perchloric acid method), needles, m. p. 189—190° (Found : C, 63·9; H, 4·2. $C_{21}H_{16}O_8$ requires C, 63·6; H, 4·0%)]. To confirm the structure of the trihydroxyflavone it was refluxed in anhydrous acetone for 6 hr. with methyl sulphate (10% excess) and potassium carbonate. The mixture was filtered. The product which separated on evaporation of the acetone did not after crystallisation depress the m. p. of an authentic sample of *5 : 8 : 2′*-trimethoxyflavone.

Some hydroxyflavones give on methylation in this way coloured sulphates which, however, are readily decomposed by treatment with boiling water, or by crystallisation from aqueous ethanol.

(2) *2′ : 3′ : 6′-Trihydroxyflavone* (II; R = H). A mixture of methyl *O*-benzylsalicylate (3·5 g.) and 2 : 3 : 6-trimethoxyacetophenone (2 g.) was refluxed with sodium powder (0·4 g.) in xylene (20 ml.) for 45 min. The product when cold was treated with damp ether and with 2% aqueous sodium hydroxide. *O-Benzylsalicyloyl-2 : 3 : 6-trimethoxybenzoylmethane*, which separated from the alkaline solution on acidification, gave a red ethanolic ferric colour and crystallised from methanol in prisms (1·5 g.), m. p. 100—101° (Found : C, 71·1; H, 6·0. $C_{25}H_{24}O_6$ requires C, 71·4; H, 5·7%). The diketone (1 g.) was heated for 1 hr. at 100° with a mixture of hydrochloric acid (5 ml.) and acetic acid (10 ml.). *2′ : 3′ : 6′-Trimethoxyflavone* (II; R = Me) which separated when the product was poured into water crystallised from methanol in prisms (0·25 g.), m. p. 158—159° (Found : C, 69·2; H, 5·3; OMe, 29·9. $C_{18}H_{16}O_5$ requires C, 69·2; H, 5·1; 3OMe, 29·8%). Demethylation with aluminium chloride in benzene [see (1)] yielded *2′ : 3′ : 6′*-trihydroxyflavone, which formed yellow needles, m. p. >340°, and gave a green ethanolic ferric colour (Found : C, 67·1; H, 3·8. $C_{15}H_{10}O_5$ requires C, 66·7; H, 3·7%). Remethylation of the trihydroxyflavone re-formed the trimethoxyflavone, m. p. and mixed m. p. 158°.

(3) *5 : 6 : 2′-Trihydroxyflavone* (IV; R = H). *2-o-Anisoyloxy-5 : 6-dimethoxyacetophenone* was prepared from 2-hydroxy-5 : 6-dimethoxyacetophenone (Baker, *J.*, 1939, 960) and was purified by extraction of its solution in benzene with 1% aqueous sodium hydroxide. It crystallised from ligroin in plates, m. p. 76° (Found : C, 65·2; H, 5·5; OMe, 27·5. $C_{18}H_{18}O_6$ requires C, 65·5; H, 5·5; 3OMe, 28·2%). The corresponding diketone was obtained as described under (1), but the mixture of ester, pyridine, and potassium hydroxide was heated for 15 min. on a steam-bath, and mechanically shaken for 24 hr. The product obtained on acidification was extracted from ether by 2% aqueous sodium hydroxide and precipitated by carbon dioxide. *o-Anisoyl-5 : 6-dimethoxysalicyloylmethane* separated from methanol in yellow needles, m. p. 59—61° (Found : C, 65·7; H, 5·6; OMe, 28·0. Required : as for the ester). For cyclisation this diketone (1·5 g.) was heated at 100° with sodium acetate (2 g.) and acetic acid (20 ml.) for 4 hr. The solid which was precipitated on dilution with water was washed with 3% aqueous sodium hydroxide and with water, and was crystallised from methanol (charcoal). *5 : 6 : 2′-Trimethoxyflavone* (IV; R = Me) separated in plates (1·1 g.), m. p. 124—125° (Found : C, 69·3; H, 5·2; OMe, 29·5. $C_{18}H_{16}O_5$ requires C, 69·2; H, 5·1; 3OMe, 29·8%), and on demethylation by aluminium chloride yielded *5 : 6 : 2′-trihydroxyflavone* which crystallised in pale yellow needles,

m. p. 274—278° (decomp.) (Found: C, 66·6; H, 4·0. $C_{15}H_{10}O_5$ requires C, 66·7; H, 3·7%), and gave a green colour with ethanolic ferric chloride. The structure was confirmed by remethylation [*triacetate*, needles, m. p. 144—146° (Found: C, 63·8; H, 4·0. $C_{21}H_{16}O_8$ requires C, 63·6; H, 4·0%)].

Demethylation of Trimethoxyflavones by Hydriodic Acid.—Formation of 5 : 6 : 2′-trihydroxyflavone from 5 : 8 : 2′-trimethoxyflavone. 5 : 8 : 2′-Trimethoxyflavone (0·5 g.) was heated for 2 hr. with hydriodic acid (*d* 1·7; 12 ml.) and phenol (6 ml.) in a sealed tube at 160—170° and the product was poured into saturated aqueous sodium hydrogen sulphite. The precipitate on crystallisation gave 5 : 6 : 2′-trihydroxyflavone in pale yellow needles, m. p. and mixed m. p. *ca.* 279° (decomp.). This result was confirmed by acetylation and remethylation to yield 5 : 6 : 2′-triacetoxy- and 5 : 6 : 2′-trimethoxy-flavone respectively (mixed m. p. confirmation).

Formation of 5 : 6 : 2′-trihydroxyflavone from 2′ : 3′ : 6′-trimethoxyflavone. 2′ : 3′ : 6′-Trimethoxyflavone was refluxed for 1½ hr. with a mixture of hydriodic acid and acetic anhydride. The product when purified in the usual way did not depress the m. p. of authentic 5 : 6 : 2′-trihydroxyflavone [see (3)]; its identity was confirmed by acetylation and remethylation. 5 : 6 : 2′-Trimethoxyflavone was demethylated without rearrangement when treated with hydriodic acid and phenol in a sealed tube at 160—170° for 1½ hr. The product was identified as 5 : 6 : 2′-trihydroxyflavone by acetylation and remethylation.

Demethylation of 7-methoxy- and 5 : 8-dimethoxy-flavone. Table 1 summarises results of experiments on the demethylation of these flavones. Standard methods of purifying the products were employed.

TABLE 1.

Demethylating agent	Time of reaction	Temp. of reaction	Yield of (1), (2), or (3) in g. from 1 g. [(1) 7-Hydroxy-, (2) 5 : 8-dihydroxy-, (3) 5 : 6-dihydroxy-flavone]
HI (*d* 1·7) in Ac_2O	1 hr.	Reflux	0·7 (1)
70% H_2SO_4	1½ hr.	,,	0·7 (1); 0·5 (3)
C_5H_5N,HCl [a]	6 hr.	200°	0·6 (1); 0·6 (2)
C_5H_5N,H_2SO_4	6 hr.	200°	0·5 (1)
$AlCl_3$ in C_6H_6	¾ hr.	Reflux	0·8 (1); 0·7 (2)
$AlBr_3$ in C_6H_6	¾ hr.	,,	0·7 (1); 0·5 (2)
$AlCl_3$–NaCl [b]	2 min.	180°	0·8 (1); 0·8 (2)

[a] No reaction at 150°. In one instance when damp pyridine hydrochloride was employed, rearrangement of 5 : 8-dimethoxyflavone to give 5 : 6-dihydroxyflavone occurred. [b] See Bruce, Sorrie, and Thomson, *J.*, 1953, 2403.

Composition of lotoflavin

(4) 5 : 7 : 2′ : 4′-*Tetrahydroxyflavone* (V; R = H).—2 : 4-*Dimethoxybenzoyl-(2-hydroxy-4 : 6-dimethoxybenzoyl)methane* which was required for the preparation of this flavone was prepared in three ways:

(*a*) 2-Hydroxy-4 : 6-dimethoxyacetophenone was condensed by the Claisen method with methyl 2 : 4-dimethoxybenzoate as described at (2) above. The alkaline extract of the diketone was saturated with carbon dioxide. The yellow solid thus obtained formed, after several recrystallisations, yellow needles, m. p. 120—121°, not altered by purification through the cupro-derivative (Found: C, 63·1; H, 5·6; OMe, 34·8. $C_{19}H_{20}O_7$ requires C, 62·3; H, 5·6; 4OMe, 34·4%). The ethanolic ferric reaction was olive-green.

(*b*) 2-Hydroxy-4 : 6-dimethoxyacetophenone was heated at 150° with methyl 2 : 4-dimethoxybenzoate in presence of sodium sand as described by Cullinane, Algar, and Ryan (*loc. cit.*; cf. Gupta and Seshadri, *loc. cit.*). The identity of the product (VIII), m. p. 120°, was confirmed by a mixed m. p. determination with the compound obtained as in (*a*) above.

(*c*) A mixture of 2-hydroxy-4 : 6-dimethoxyacetophenone (3 g.), 2 : 4-dimethoxybenzoic anhydride (30 g.), and freshly distilled triethylamine (12 ml.) was heated in nitrogen for 4 hr. at 170°. The product was refluxed with aqueous potassium hydroxide (23 g. in 35 ml. of H_2O) until a clear solution was produced (7 min.). The yellow solid obtained on treatment of the solution with carbon dioxide gave on repeated crystallisation the required diketone in yellow needles (1·0 g.), m. p. 120—121°, not depressed by addition of the diketone prepared as in (*a*) above.

The effect of addition of methyl sulphate in the Claisen condensation [see (*c*) above] was tested as follows: 2-Hydroxy-4 : 6-dimethoxyacetophenone (1·7 g.), methyl 2 : 4-dimethoxybenzoate (2·5 g.), sodium sand (0·3 g.), and methyl sulphate (0·3 ml.) were heated at 150° for

2 hr. The product was treated with damp ether and with water. 2 : 4 : 6-Trimethoxyacetophenone (0·5 g.) was obtained from the ethereal layer. The aqueous portion yielded 2 : 4-dimethoxybenzoyl-(2 : 4 : 6-trimethoxybenzoyl)methane (0·15 g.), m. p. 153° (Found : C, 64·1; H, 5·9; OMe, 41·0. Calc. for $C_{20}H_{22}O_7$: C, 64·2; H, 5·9; 5OMe, 41·4%). This was the compound (m. p. 151°) (IX) obtained by Cullinane *et al.* and by Gupta and Seshadri (*locc. cit.*) who considered it to be (VIII) which, however, has m. p. 120°. We are indebted to Professor Seshadri for a sample of his material (IX), m. p. 151°, which enabled us to confirm its constitution.

5 : 7 : 2′ : 4′-Tetramethoxyflavone (V; R = Me) was obtained by cyclisation of 2 : 4-dimethoxybenzoyl-(2-hydroxy-4 : 6-dimethoxybenzoyl)methane as described at (1). It formed needles, m. p. 179—180° (Found : C, 66·6; H, 5·4; OMe, 36·3. Calc. for $C_{19}H_{18}O_6$: C, 66·7; H, 5·3; 4OMe, 36·2%). Cullinane *et al.* (*loc. cit.*) give m. p. 186° for tetramethoxyflavone. The ethanolic ferric reaction was negative. Demethylation of the tetramethoxyflavone by aluminium chloride in benzene yielded 5 : 7 : 2′ : 4′-tetrahydroxyflavone which after purification through the tetra-acetate had m. p. 334—336° (Found : C, 62·9; H, 3·8. Calc. for $C_{15}H_{10}O_6$: C, 62·9; H, 3·5%). The ethanolic ferric reaction was reddish-brown [tetra-acetate, m. p. 159° (Found : C, 60·5; H, 4·1. Calc. for $C_{23}H_{18}O_{10}$: C, 60·8 H, 4·0%)]. Robinson and Venkataraman (*J.*, 1929, 67) give m. p. 332—335° for the flavone and m. p. 159° for the tetra-acetate.

(5) 7 : 2′ : 4′ : 6′-*Tetrahydroxyflavone* (VI; R = H).—*Methyl 2-benzyloxy-4-methoxybenzoate*, which was prepared from the corresponding 2-hydroxy-compound by using potassium carbonate, acetone, and benzyl chloride, separated from methanol in needles, m. p. 64° (Found : C, 71·1; H, 6·1. $C_{16}H_{16}O_4$ requires C, 70·6; H, 5·9%), and gave a purple ethanolic ferric colour. A mixture of the above ester (3 g.) and 2 : 4 : 6-trimethoxyacetophenone (2 g.) in dry ether was added to sodium sand (0·6 g.). The solvent was evaporated and the residue heated for 2 hr. on a steam-bath ($CaCl_2$ guard). The product was treated with damp ether and purified as described at (2). *O-Benzyl-4-methoxysalicyloyl-(2 : 4 : 6-trimethoxybenzoyl)methane* separated from methanol in needles, m. p. 141° (Found : C, 69·2; H, 6·1. $C_{26}H_{26}O_7$ requires C, 69·3; 5·8%). The ethanolic ferric colour was red. On debenzylation and cyclisation [see (2)], the diketone yielded 7 : 2′ : 4′ : 6′-*tetramethoxyflavone* (VI; R = Me) which crystallised in plates, m. p. 197° (Found : C, 66·5; H, 5·4; OMe, 36·0. $C_{19}H_{18}O_6$ requires C, 66·7; H, 5·3; 4OMe, 36·2%). This flavone (0·2 g.) was heated at 210—220° for 5 min. with aluminium chloride (3 g.) and sodium chloride (1·5 g.) (Bruce, Sorrie, and Thomson, *J.*, 1953, 2403). The product, when worked up as in normal demethylation by aluminium chloride [see (1) above], gave 7 : 2′ : 4′ : 6′-*tetrahydroxyflavone*, which separated from ethyl acetate or aqueous acetic acid in pale yellow, hygroscopic, aggregates (0·1 g.), m. p. 303—304° (decomp.). The flavone exhibited a dark blue fluorescence in sulphuric acid (Found : C, 62·3; H, 3·8. $C_{15}H_{10}O_6$ requires C, 62·9; H, 3·5%) [*tetra-acetate*, m. p. 136—137° (from ligroin) (Found : C, 60·6; H, 4·0. $C_{23}H_{18}O_{10}$ requires C, 60·8; H, 4·0%)]. Remethylation (potassium carbonate–methyl sulphate–acetone) gave the tetramethoxyflavone (mixed m. p. confirmation).

Formation of 5 : 7 : 2′ : 4′-*Tetrahydroxyflavone from* 7 : 2′ : 4′ : 6′-*Tetramethoxyflavone.*—7 : 2′ : 4′ : 6′-Tetramethoxyflavone was refluxed for 2 hr. at 160° with hydriodic acid and phenol in an atmosphere of carbon dioxide. The product was purified in the usual way and acetylated. The tetra-acetate thus obtained had m. p. 159°. This m. p. was not depressed by the addition of an authentic sample of 5 : 7 : 2′ : 4′-tetra-acetoxyflavone.

Formation of 5 : 7 : 2′ : 4′-*Tetrahydroxyflavone* (V; R = H) *from* 2 : 4-*Dimethoxybenzoyl-(2 : 4 : 6-trimethoxybenzoyl)methane* (IX).—2 : 4-Dimethoxybenzoyl-(2 : 4 : 6-trimethoxybenzoyl)-methane (Cullinane *et al.*, *loc. cit.*) was refluxed with hydriodic acid (*d* 1·94) for 4 hr. The crude flavone which separated when the mixture was poured into aqueous sodium hydrogen sulphite was crystallised and acetylated (acetic anhydride–perchloric acid). The product when crystallised from ethanol and then from ethyl acetate had m. p. 159°, not depressed by addition of authentic 5 : 7 : 2′ : 4′-tetra-acetoxyflavone. Cullinane *et al.* (*loc. cit.*) considered that the product (m. p. 171°) which they obtained by the mild action of hydriodic acid on (IX) was 7 : 2′ : 4′ : 6′-tetramethoxyflavone (m. p. 197°; see above). As it gave a green ethanolic ferric colour it was most probably 5 : 7 : 2′ : 4′-tetramethoxyflavone (m. p. 180°) with the m. p. depressed by some demethylation in the 5-position. 5 : 7 : 2′ : 4′-Tetramethoxyflavone was demethylated without rearrangement when treated for 2 hr. with hydriodic and phenol at 170° in a sealed tube. This result was confirmed by acetylation and remethylation (cf. Gupta and Seshadri, *loc. cit.*).

(6) 5-*Hydroxy*-3 : 7 : 3′-*Trimethoxyflavone.*—5 : 7-Dihydroxy-3 : 3′-dimethoxyflavone, m. p. 240°, was prepared by the Allan–Robinson fusion method as described by Shaw and Simpson (*J.*, 1952, 5031) (Found : C, 65·0; H, 4·6; OMe, 19·0. Calc. for $C_{17}H_{14}O_6$: C, 65·0; H, 4·5; 2OMe, 19·0%) [diacetate, m. p. 143°]. Shaw and Simpson (*loc. cit.*) give m. p. 245—246° for the flavone

and m. p. 143° for the diacetate. It was found advantageous to use triethylamine (Kuhn and Löw, *Ber.*, 1944, **77**, 196) in place of sodium *m*-methoxybenzoate in the fusion. The *m*-methoxybenzoic anhydride required was prepared (60% yield) by the process described by Robinson and Venkataraman (*J.*, 1929, 63) for the preparation of 2 : 4-dimethoxybenzoic anhydride. This flavone on partial methylation by methyl sulphate–potassium carbonate–acetone (Sastri and Seshadri, *Proc. Indian Acad. Sci.*, 1946, **23**, *A*, 262) yielded *5-hydroxy-3 : 7 : 3'-trimethoxyflavone* in yellow needles, m. p. 99—101° (Found : C, 65·9; H, 4·9; OMe, 28·0. $C_{18}H_{16}O_6$ requires C, 65·9; H, 4·9; 3OMe, 28·4%). The ethanolic ferric reaction was green. *5-Acetoxy-3 : 7 : 3'-trimethoxyflavone* had m. p. 164—165° (Found : C, 64·7; H, 4·8. $C_{20}H_{18}O_7$ requires C, 64·9; H, 4·9%). Dunstan and Henry (*Phil. Trans.*, 1901, **194**, *B*, 515) give m. p. 125° and 175° for the dimorphic trimethyl ether of lotoflavin and m. p. 147° for the monoacetyl derivative of the ether. 3 : 5 : 7 : 3'-Tetra-acetoxyflavone had m. p. 180—182°. Shaw and Simpson (*loc. cit.*) give m. p. 177—180° for this compound and Dunstan and Henry (*loc. cit.*) give m. p. 176—178° for lotoflavin tetra-acetate.

(7) *5 : 7 : 3' : 5'-Tetrahydroxyflavone.*—*2-(3 : 5-Dimethoxybenzoyloxy)-4 : 6-dimethoxyacetophenone* (prep. by the pyridine–acid chloride method) separated in plates, m. p. 136—137° (Found : C, 63·4; H, 5·6; OMe, 34·3. $C_{19}H_{20}O_7$ requires C, 63·3; H, 5·6; 4OMe, 34·4%). This ester was transformed by treatment with potassium hydroxide in pyridine at 60° for 4 hr. The resulting diketone, *3 : 5-dimethoxybenzoyl-(2-hydroxy-4 : 6-dimethoxybenzoyl)methane*, formed yellow needles, m. p. 139—140° (Found : C, 62·9; H, 5·5; OMe, 34·8. Required : as for the ester). The ethanolic ferric reaction was green. *5 : 7 : 3' : 5'-Tetramethoxyflavone* crystallised in needles, m. p. 201—202° (Found : C, 66·3; H, 5·4; OMe, 36·6. $C_{19}H_{18}O_6$ requires C, 66·7; H, 5·3; 4OMe, 36·2%). *5 : 7 : 3' : 5'-Tetrahydroxyflavone* was obtained by demethylation of the tetramethoxyflavone for 2 hr. at 170° by hydriodic acid and phenol. This tetrahydroxyflavone separated from aqueous acetic acid in pale yellow needles, darkening *ca.* 280°, m. p. above 330° (Found : C, 55·9, 56·1; H, 4·4, 4·4. $C_{15}H_{10}O_6,2H_2O$ requires C, 55·9; H, 4·3%). Attempts to dry this flavone at temperatures between 100° and 160° resulted in a product with indefinite amounts of water. *5 : 7 : 3' : 5'-Tetra-acetoxyflavone*, prepared by the sodium acetate–acetic anhydride method, crystallised in plates, m. p. 198—200° (Found : C, 60·5; H, 4·0. $C_{23}H_{18}O_{10}$ requires C, 60·8; H, 4·0%).

Chromatographic and spectrographic comparison of lotoflavin and other flavones. Samples of the specimen of lotoflavin made available by Professor Algar were run on paper (cf. Nordström and Swain, *J.*, 1953, 2764) against 5 : 7 : 4'-trihydroxyflavone (apigenin), 5 : 7 : 2' : 4'-tetrahydroxyflavone, 5 : 7 : 3' : 4'-tetrahydroxyflavone (luteolin), 5 : 7 : 4'-trihydroxyflavonol (kæmpferol), 5 : 7 : 2' : 4'-tetrahydroxyflavonol (morin), 5 : 7 : 3' : 4'-tetrahydroxyflavonol (quercetin), 5 : 3' : 4'-trihydroxy-7-methoxyflavonol (rhamnetin), 5 : 7 : 4'-trihydroxy-3'-methoxyflavonol (*iso*rhamnetin), and 5 : 7 : 3' : 4' : 5'-tetrahydroxyflavonol (myricetin). The solvent systems were : (1) acetic acid–water–concentrated hydrochloric acid (30 : 10 : 3) (Bate-Smith, *Biochem. J.*, 1954, **58**, 122); (2) butanol–acetic acid–water (6 : 1 : 2) (Nordström and Swain, *loc. cit.*); (3) butanol–water.

Rhamnetin and *iso*rhamnetin were not run with solvent system (2). The chromatograms were inspected in ultraviolet light before and after treatment with ammonia vapour. Lotoflavin gave two spots; the major component ran with quercetin and the minor with kæmpferol.

Lotoflavin, kæmpferol, quercetin, rhamnetin, and *iso*rhamnetin were also run, in solvent (3), on plain and borate-buffered papers. Quercetin and the main constituent from lotoflavin did not travel. The minor component ran normally with kæmpferol; rhamnetin moved slightly, and *iso*rhamnetin normally.

The ultraviolet absorption maxima of lotoflavin and quercetin are recorded in Table 2.

TABLE 2. $\lambda_{max.}$ *of lotoflavin and quercetin and their acetates in* EtOH, 0·002M-NaOEt, *and ethanolic* 0·1% $AlCl_3$.

	In EtOH		In 0·002M-NaOEt	In 0·1% $AlCl_3$	
Lotoflavin	255	370	335	270	430
,, acetate	252	298	—	252	298
Quercetin	255	370	335	270	430
,, acetate	252	298	—	252	298

The infrared spectra of lotoflavin and quercetin as paraffin oil mulls were determined with a Grubb-Parsons S3A single-beam spectrometer, corresponding peaks being obtained as follows : 6·05, 6·24, 6·43, 6·59, 8·24, 8·36, 8·57, 8·88, 9·19, 9·88, 10·22, 10·70, 11·57, 11·86, 11·94 μ.

Microdegradation of lotoflavin. Lotoflavin (*ca.* 0·1 mg.) was fused with potassium hydroxide (100 mg.) for 1 min., and the product was rapidly cooled and dissolved in water. The solution was acidified to approx. pH 3 by dilute hydrochloric acid and extracted with ether. The ethereal solution was washed with water (0·5 ml.), and the solvent removed. The residue was dissolved in ethanol and run on paper [solvent system: butan-1-ol–acetic acid–water (6 : 1 : 2)] against phloroglucinol, phloracetophenone, protocatechuic acid, and β-resorcylic acid. The spots from the degradation product and from quercetin, on similar treatment, ran with phloroglucinol and protocatechuic acid. For inspection the papers were sprayed with diazotised *p*-nitroaniline and over-sprayed with 0·1N-sodium hydroxide (Bate-Smith and Swain, *J.*, 1953, 2187; Swain, *Biochem. J.*, 1952, **53**, 200).

Acetylation of lotoflavin. Lotoflavin (19m g.) was acetylated by acetic anhydride–perchloric acid. The product separated in needles, m. p. 190° [Found: C, 59·1, 58·7; H, 4·0, 3·9. Calc. for $C_{15}H_5O_2(OAc)_5$: C, 58·6; H, 3·9. Calc. for $C_{15}H_6O_2(OAc)_4$: C, 60·8; H, 4·0%]. This acetate did not depress the m. p. of authentic quercetin penta-acetate. The ultraviolet spectra of both acetates were determined in ethanol and ethanolic 0·1% aluminium chloride solution. The results are given in Table 2.

Approximate percentage of kæmpferol in lotoflavin. Ethanolic solutions of mixtures (0·5 mg.) of kæmpferol (1, 5, 10%) and quercetin were run on No. 3 Whatman paper (3·5 cm. strip) in solvent system (1). Each kæmpferol strip was eluted with spectroscopic ethanol, and the elution volume was made up to 25 ml. The absorption (at 368 mμ) of the solution was determined and compared with a curve showing absorption (at 368 mμ) against concentration for ethanolic solutions of kæmpferol. A relation between kæmpferol taken and kæmpferol found by chromatography was thus obtained. Lotoflavin when chromatographed under the same conditions as the synthetic mixtures of kæmpferol and quercetin showed 1—2% of kæmpferol.

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Properties and Reactions of Alkyl Free Radicals in Solution. Part VIII. The Reducing Action of Some Water-soluble Radicals.*

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4 : 4′-Azobis-4-cyanopentanoic acid has been prepared and separated into its *meso*- and racemic isomers. When heated in aqueous solution each isomer gives in about 20% yield a mixture in equal proportions of the *meso*- and the racemic form of 4 : 5-dicyano-4 : 5-dimethyloctane-1 : 8-dioic acid.

The free radicals produced from this acid, from 4 : 4′-azobis-4-cyanoheptane-1 : 7-dioic acid, and from two of the azo-compounds previously studied (Part II, *J.*, 1951, 1851) have been found to reduce a number of inorganic reagents and also certain oxidation–reduction indicators. It is concluded that for these radicals E_{-e}, for the reaction $R^{\bullet} \rightleftharpoons R^{+} + e$, must be slightly less than +0·4 v.

The magnitudes of the two redox potentials, E_{+e} and E_{-e}, of free radicals, for electron gain and electron loss respectively, have been shown to be of significance in the elucidation of the mechanisms of both oxidation and reduction processes (Mackinnon and Waters, *J.*, 1953, 323; Drummond and Waters, *J.*, 1954, 2456). Though redox potentials of such transient entities as organic free radicals can be assessed approximately by relation to the properties of inorganic ions in aqueous solution, as yet suitable active radicals have rarely

* Part VII, *J.*, 1954, 1920.

been prepared in water except as transient intermediates in sequences of electron-transfer reactions which are difficult to analyse into their component stages.

Whilst many types of free radicals have been made by the homolysis of azo- and diazo-compounds (cf. *Ann. Reports*, 1952, **49**, 115—121) little attention seems to have been paid to the practicability of synthesising aliphatic azo-compounds which, by virtue of acidic or basic substituents, could be made to generate in aqueous solution organic free radicals of one known structure only. We are now engaged in exploring this approach to the assessment of free-radical reactivity.

One water-soluble aliphatic azo-compound, 4 : 4′-azobis-4-cyanopentanoic acid (I), has evidently been prepared by Madison Hunt (U.S.P., 2,471,959/1949) and by Lewis and Matheson (*J. Amer. Chem. Soc.*, 1949, **71**, 747) from lævulic acid, but no details concerning this substance, other than a rate of decomposition, have been reported. This azo-acid contains two identical asymmetric centres and should therefore exist in *meso*-, racemic,

$$[\text{N}{:}\text{CMe(CN)}{\cdot}\text{CH}_2{\cdot}\text{CH}_2{\cdot}\text{CO}_2\text{H}]_2 \longrightarrow {\cdot}\text{CMe(CN)}{\cdot}\text{CH}_2{\cdot}\text{CH}_2{\cdot}\text{CO}_2\text{H} \longrightarrow [{\cdot}\text{CMe(CN)}{\cdot}\text{CH}_2{\cdot}\text{CH}_2{\cdot}\text{CO}_2\text{H}]_2$$

(I) Either (±)- or *meso* (II) ? Enantiomorphs (III) Both (±)- and *meso*

and optically active forms. We have prepared it and have been able to separate the *meso*- and the racemic form by taking advantage of their difference in solubility in both water and aqueous methanol but have failed to identify them by achieving the resolution of one—the need to work only in cool solutions adds great difficulties to available techniques of optical resolution. Aqueous solutions of the isomeric free acids, and also their solutions in alkali, decompose when warmed, to give free radicals that can catalyse the polymerisations of vinyl cyanide, vinyl acetate, and methyl methacrylate (cf. Hunt, *loc. cit.*). Also the acids have been shown to catalyse the side-chain chlorination of toluene by sulphuryl chloride (cf. Part II, *J.*, 1951, 1851). The decompositions of each of the isomers (I) in water at about 90° gave about 22% of mixtures of 4 : 5-dicyano-4 : 5-dimethyloctane-1 : 8-dioic acids (III), from which *meso*- and (±)-isomers were successfully separated. Overberger and Berenbaum (*J. Amer. Chem. Soc.*, 1951, **73**, 4883) have claimed that a similar separation of the *meso*- and the (±)-form of αβ-di*iso*butyl-αβ-dimethylsuccinonitrile from the decompositions of both the pure *meso*- and the pure (±)-form of αα′-azobis-αγ-dimethylvaleronitrile indicates that the free radicals CRR′(CN)· have a planar structure, but this argument is not valid, for if the homolyses of both the *meso*- and the (±)-form of the azo-nitriles liberated enantiomorphous (+)- and (−)-radicals then at all times during the decomposition both these would be present in equivalent amounts from each starting material and would, by random combination, necessarily yield 50% each of the *meso*- and the (±)-dimer of type (III).

The major product of the decomposition of the acid (I) was a very soluble gum which immediately reduced cold permanganate. This unsaturation indicates that the gum consists mainly of the products of disproportionation of the radicals (II). It is not a product of their reaction with water since a decomposition of the acid (I) in chlorobenzene yielded a similar gum and an even smaller percentage of dimers (III).

A more symmetrical water-soluble azo-compound, 4 : 4′-azobis-4-cyanoheptanedioic acid, has also been prepared from γ-oxopimelic acid. Its decomposition in water yields only 10% of the radical dimer, 4 : 5-di-(2-carboxyethyl)-4 : 5-dicyano-octanedioic acid. Since dialkylazonitriles yield 50—80% of dimers it appears that the presence of carboxyl substituents in free alkyl radicals reduces their tendency to dimerise.

Cold aqueous solutions of the aliphatic azo-compounds mentioned above show no reducing properties, but when these solutions are heated, under nitrogen or carbon dioxide on a boiling-water bath, many substances can be reduced as the organic free radicals are generated. Similar experiments have been carried out with αα′-azobis*iso*butyronitrile and αα′-azobis-α-methylbutyronitrile in dilute aqueous alcohol (Table 1). Corresponding tests have also been carried out with representative oxidation–reduction indicators of known E_0'. These gave less convincing evidence of the ease with which free alkyl radicals can lose electrons, for the indigosulphonates and the quinonoid indophenol dyes were irreversibly decolorised, presumably by addition of radicals to their quinonoid systems (cf. Parts I and V, *J.*, 1950, 1764; 1952, 4666; Part VII, *loc. cit.*).

Table 1 indicates that for the four radicals tested the value of E_{-e} (for the reaction $R\cdot \rightleftharpoons R^+ + e$) must be slightly less than +0·4 v, the standard hydrogen electrode being

TABLE 1. *Reactions of inorganic oxidising agents with aliphatic free radicals.*

Reagent	Standard redox potential, E_0 (v)	Reactions with radicals * A	B	C	D
Acid permanganate	1·5	Reduced to Mn^{2+}		—	—
Acid dichromate	1·3	Reduced to Cr^{3+}		—	—
Bromine water	1·06	Decolorised		See Part II (*J.*, 1951, 1851)	
Ammoniacal silver nitrate	(0·8)	Reduced to silver		Reduced	
Selenious acid	0·74	*p*H 2, red. to Se	pH 2, red.: pH 7, not reduced	Not reduced	
Ferric chloride (acid)	0·74	Red. to Fe^{2+}	Slight reduction	Slight reduction	
Mercuric chloride (pH 7)	0·6	Reduced to mercurous chloride			
Iodine	0·54	Decolorised rapidly		See Part II	
Potassium ferricyanide (pH 7)	0·49	Ferrocyanide formed		—	Slow reduction
Ammonium vanadate (pH 7)	0·4	Red. through $(VO_2)^{2+}$ to V^{3+}	Red. to V^{3+}	Reduced to V^{3+} at pH 2, but not reduced at pH 7	
Fehling's solution	—	$Cu_2O\downarrow$	$Cu_2O\downarrow$	Very slight reduction	
Stannic chloride	(0·13)	Not reduced		—	—
Folin's phenol reagent (pH 7) (molybdate)	—	Slight reduction		Slight reduction At pH 1, no reduction	

* *Radicals used:* *A*, ·CMe(CN)·CH_2·CH_2·CO_2H in H_2O. *B*, ·C(CN)(CH_2·CH_2·CO_2H)$_2$ in H_2O. *C*, ·CMe_2·CN in aq. alcohols. *D*, ·CMeEt·CN in aq. alcohols

the reference zero. Table 2 indicates that the corresponding value of E' at pH 7 is 0·0 to −0·1 v, and since $E_0' = 0{\cdot}0$ corresponds to $E_0 = +0{\cdot}42$ for reactions involving hydrogen transfer the two sets of observations are concordant. The free radicals CRR′(CN)· do not reduce tetrazolium salts and are therefore less powerful reducing agents than the radicals

TABLE 2. *Reactions of aliphatic free radicals with oxidation–reduction indicators.*

Indicator	Redox potential E'_0 (v) (at pH 7)	Reactions with radicals * A	B	C	D
Phenolindo-2 : 6-dichlorophenol	+0·0226	Irreversibly decolorised			
Phenol-indophenol	+0·220	,,		,,	
2-Chlorophenol-indophenol	+0·200	,,		,,	
Lauth's violet	+0·056	Reversibly decolorised			
Methylene-blue	+0·011	Reversibly decolorised (slight action only)			
Potassium indigotetrasulphonate	−0·046	Irreversibly decolorised			
Potassium indigodisulphonate	−0·123		,,	,,	
2 : 3 : 5-Triphenyltetrazolium chloride	—	Not attacked	—	—	—

* See footnote to Table 1.

CHMe(OH)· and CMe_2(OH)· formed from ethanol and propan-2-ol by Fenton's reagent (Mackinnon and Waters, *loc. cit.*). This difference was expected since the electron-withdrawing CN groups of these radicals should diminish their tendency to suffer further electron loss.

EXPERIMENTAL

4 : 4′-*Azobis*-4-*cyanopentanoic Acids*.—To sodium cyanide (49 g.) and hydrazine sulphate (65 g.) in water (500 ml.) at 50° was added during 30 min. with rapid stirring a neutralised solution of lævulic acid (116 g.) in water (200 ml.). The solution was stirred at 45—50° for a further 3 hr. and then allowed to cool. It was then made just acid to litmus, cooled in ice, stirred rapidly, treated dropwise with bromine until the latter just remained in excess, and stirred for a further 30 min. The excess of bromine was destroyed with sodium hydrogen sulphite, and the white solid which had separated (73 g.) was collected and washed once with

ice-water. It had m. p. 115—127° and was a mixture of *meso*- and (±)-isomers (Found : equiv., 138. Calc. for $C_{12}H_{16}O_4N_4$: equiv., 140).

A portion of the dry acid was shaken with 25 ml. of water; after 1 hr. the saturated solution was filtered, the solid residue was shaken with a further 25 ml. of water, and this whole procedure was repeated a number of times. Each portion of aqueous extract was titrated with alkali. Plotting of the successive titres indicated that the acid was a mixture of two components, the more soluble (48% of the whole) having a solubility of 2·75 g./l. and the less soluble 0·47 g./l. at room temperature. A similar determination in 10% methanol indicated that the more soluble isomer might be dissolved completely from 1 g. of mixed acids by 60 ml. of this solvent. By a separation in this way the less soluble *acid*, after crystallisation from warm water, was obtained as needles, m. p. 128° (decomp.) (Found : C, 51·3; H, 5·9; N, 20·0. $C_{12}H_{16}O_4N_4$ requires C, 51·4; H, 5·7; N, 20·0%). The more soluble *isomer*, recovered by careful evaporation of the solvent under diminished pressure and crystallisation from small volumes of warm water, had m. p. 110—111° (decomp.) (Found : C, 50·8; H, 5·8; N, 19·4%). Attempted resolution of the more soluble isomer by brucine in acetone gave impure resinous salts, of which the most and the least soluble fraction had α_D −47° and −57° respectively, but the regenerated free acids had no detectable activity. The brucine salts of the more soluble acid could be obtained only as resins the specific rotations of which were almost identical for all fractions. The use of strychnine was even less successful.

Decomposition of the 4 : 4′-*Azobis*-4-*cyanopentanoic Acids*.—The more soluble acid (5 g.) in water (200 ml.) was heated on a steam-bath until evolution of nitrogen had ceased (5 hr.). On cooling, 0·6 g. of a brownish solid, m. p. 195—207°, was deposited. Partial evaporation gave 0·4 g. of a white solid, m. p. 173—179°, and complete evaporation of the remainder a brown gum, of which 1 g. proved to be insoluble in dry acetone and could be separated as a powder, m. p. 120—175°. The acetone-soluble part of the gum immediately reduced cold permanganate; attempts to prepare crystalline solids from it failed. From the solid of high m. p. repeated crystallisation from ethanol gave the less soluble isomer of 4 : 5-*dicyano*-4 : 5-*dimethyloctane*-1 : 8-*dioic acid* in needles, m. p. 207—208° (Found : C, 57·3; H, 6·1; N, 10·8%; *M*, 272. $C_{12}H_{16}O_4N_2$ requires C, 57·2; H, 6·4; N, 11·1%; *M*, 252). From the powder of lower m. p. repeated crystallisation from water gave the more soluble *isomer*, m. p. 182—183° (Found : C, 56·9; H, 6·4; N, 11·2%; *M*, 280). Both isomers were also obtained in similar yields (10—14%) by decomposing the less soluble azo-acid in water. The total yield of 4 : 5-dicyano-4 : 5-dimethyloctane-1 : 8-dioic acids obtained by decomposition in water of a larger bulk of the mixed azo-acids was 22%. Decomposition in chlorobenzene solution at 100° gave only 13% of these isomers, again in nearly equal proportions.

4 : 4′-*Azobis*-(4-*cyanoheptanedioic*) *Acid*.—γ-Oxopimelic acid (Marckwald, *Ber.*, 1887, **20**, 2813) (35 g., 0·2 mole) neutralised with sodium carbonate solution (200 c.c.) was added slowly to a stirred mixture of sodium cyanide (0·2 mole) and hydrazine sulphate (0·1 mole) in water (200 c.c.) at 45°. Stirring was continued at this temperature for 3 hr. after the addition. After a further 24 hr. the solution was acidified, cooled to 0°, and oxidised with bromine as described above. The white powder which was deposited was collected (15·5 g., 39%) and crystallised from warm aqueous ethanol; it had m. p. 133—135° (decomp.) (Found : C, 48·5; H, 5·3; N, 14·0. $C_{15}H_{20}O_8N_4$ requires C, 48·5; H, 5·1; N, 14·1%). This *acid* (20 g.) was decomposed in boiling water (200 c.c.); the resulting solution after evaporation to half its bulk deposited 1·8 g. (10%) of 4 : 5-*di*-(2-*carboxyethyl*)-4 : 5-*dicyano-octanedioic acid*, m. p. 252—254° (from aqueous methanol) (Found : C, 52·6; H, 5·5; N, 7·3. $C_{16}H_{20}O_8N_2$ requires C, 52·3; H, 5·5; N, 7·6%). The remainder of the decomposition product was a very soluble unsaturated gum.

Decompositions of the Azo-compounds in the Presence of Oxidising Agents.—(*a*) With inorganic oxidising agents the tests were carried out by heating the azo-compound (0·1 g.) in water (20 ml.) with 0·5 equiv. of reagent for 30 min. on a boiling-water bath and treating similarly a control tube containing the oxidising agent and distilled water. When the reduced product might be affected by air, then nitrogen or carbon dioxide was bubbled continuously through both tubes.

(*b*) With organic oxidation–reduction indicators the pH of the solutions was always adjusted to 7·0 by a phosphate buffer, and a stream of nitrogen was bubbled through the apparatus to exclude air. Tests were carried out by adding 5 ml. of a 0·2% solution of the indicator in water to 0·1 g. of the azo-compound in 25 ml. of aqueous solution. This mixture was heated under reflux as before, together with a control tube containing indicator and buffer solution only. Since the azo-compounds *C* and *D* were insoluble in water a little ethanol or propan-2-ol was added to promote dissolution (this did not appear to affect the results, for similar, but less reliable, results were obtained with dispersions of the molten azo-compounds in hot water).

The results are given in the Tables. The reversibility of the reduction was tested by exposing the cooled decolorised solutions to air. Only with methylene blue and thionine did the original colour of the dye reappear.

One of us (R. M. H.) thanks the Department of Scientific and Industrial Research for a maintenance grant held during part of this investigation.

THE DYSON PERRINS LABORATORY, OXFORD. [*Received, June 1st*, 1955.]

Griseoviridin. Part I.

By D. E. AMES, R. E. BOWMAN, J. F. CAVALLA, and D. D. EVANS.

[Reprint Order No. 6523.]

The formula $C_{22}H_{29}O_7N_3S$ is proposed for griseoviridin, a *Streptomyces* antibiotic. Some chemical studies bearing on the nature of the functional groups in griseoviridin are described.

Two antibiotics, griseoviridin and viridogrisein, were isolated from cultures of a strain of *Streptomyces griseus*, and also from an unidentified *Streptomyces* strain, by Bartz, Standiford, Mold, Johannessen, Ryder, Maretzki, and Haskell (2nd Ann. Symp. on Antibiotics, Washington, October, 1954; Antibiotics Annual, 1954—5). Griseoviridin was reported to be a colourless, neutral, optically active compound which gives negative results with ferric chloride, in the Sakaguchi reaction, and in the Jacobs–Hoffman test for unsaturated lactones. We now describe some studies on the degradation of this material which was kindly supplied by Dr. Bartz and his colleagues.

Griseoviridin crystallises well from pyridine or methanol and retains solvent tenaciously, but the dried material gives satisfactory analyses for the formula $C_{22}H_{29}O_7N_3S$ (though the hydrogen value is not conclusively proved). The corresponding molecular weight was consistent with the values obtained by the isothermal-distillation method and by *X*-ray examination (carried out by Dr. G. W. R. Bartindale). The antibiotic does not contain thiol, methoxyl, or methylimino-groups, but about five active hydrogen atoms were detected by the Zerewitinov method. Griseoviridin gives a positive result in the chromate–nitric acid test for alcohols, but it is not a vicinal diol, for there is only slight reaction with periodic acid. No titratable groups could be detected by potentiometric titration of griseoviridin even with perchloric acid in acetic acid (Hall, *J. Amer. Chem. Soc.*, 1930, **52**, 5115; Markunas and Riddick, *Analyt. Chem.*, 1951, **23**, 337); it is, therefore, concluded that all three nitrogen atoms are present in amide-type groups, and it is also likely that amide-NH groups account for several of the observed active hydrogen atoms. The ultraviolet light absorption of griseoviridin ($\lambda_{max.}$ 2205 Å, ε 44,000) appears to indicate the presence of at least three chromophoric groups, such as $\alpha\beta$-unsaturated acid residues. Consideration of the infrared spectrum is deferred to Part II (following paper).

Acetylation of griseoviridin with acetic anhydride–pyridine yields a diacetyl derivative, $C_{26}H_{33}O_9N_3S$, which is regarded as the *OO*-diacetate, but several attempts to prepare a benzoyl derivative gave only gums. Treatment of griseoviridin with acetic anhydride–acetic acid–perchloric acid furnished a well-defined perchlorate diacetate. It therefore appears that griseoviridin contains two hydroxyl groups and, as shown in the sequel, this conclusion is supported by the isolation of diacetyl derivatives from hydrogenation and desulphurisation reactions. The potentiometric titration curve of the perchlorate diacetate showed only one break (pK_a 6·25) corresponding to two equivalents of alkali; one of these must correspond to the liberation of a weak base from its perchlorate, and the other is presumably due to a weakly acidic group such as an enolic system. This view is supported by the fact that, after treatment with hot water or alkali, the perchlorate gave a purple colour with ferric chloride. Attempts to hydrogenate griseoviridin under various conditions gave unsatisfactory results owing mainly to its insolubility in suitable solvents. In quantitative micro-hydrogenations of the acetylation products considerably more than two mols. of hydrogen were absorbed, but accurate data were not obtained because the rate of absorption declined continually, possibly as a result of the poisoning effect of the sulphur on the

catalyst. The acetylation product could, however, be hydrogenated in the presence of a large amount of palladium (on charcoal or strontium carbonate) to give a crystalline product, probably hexahydrogriseoviridin diacetate. The absorption spectrum ($\lambda_{max.}$ <2150 Å; ε 21,000) showed that at least one chromophoric group is still present in this compound.

On treatment of griseoviridin diacetate with perbenzoic acid, two mols. of per-acid were rapidly consumed, the greatly reduced intensity of light absorption ($\lambda_{infl.}$ 2100 Å; $E^{1\%}_{1cm.}$369 in EtOH) showing that reaction had occurred at double bonds (*i.e.*, not sulphide to sulphone). Since αβ-unsaturated acid residues are not usually attacked by perbenzoic acid, reaction may well have occurred at a diene system. It is of interest that the absorption spectrum of this product was almost identical with that of hexahydrogriseoviridin diacetate.

The reaction of griseoviridin with diazomethane yielded much yellow gum, and a small quantity of a colourless, crystalline compound, $C_{23}H_{31}O_7N_3S$. This does not contain a methoxyl group or any titratable group, and its ultraviolet and infrared spectra closely resemble those of griseoviridin. In Kuhn–Roth determinations this compound gave considerably higher values than those obtained from griseoviridin itself; this may be due to *C*-methylation or to *cyclo*propane ring formation.

Alkaline hydrolysis of griseoviridin yields ammonia (1 mol.) and on acidification, hydrogen sulphide (*ca.* ½ mol.). No lead sulphide is precipitated on treatment of the alkaline hydrolysate with alkaline lead acetate solution, indicating that hydrolysis produces an acid-labile sulphur compound, and not sodium sulphide. Two or three titratable groups are generated during alkaline hydrolysis, according to the conditions, but one of these recombines in faintly acid solution within a few hours.

Acetic acid was detected in griseoviridin hydrolysates by paper chromatography. Acetyl-value determinations, however, gave very small results (*ca.* 0·2—0·5%) and it is therefore concluded that griseoviridin does not contain an *O*- or *N*-acetyl group but that some acetic acid is produced by hydrolytic degradation. Kuhn–Roth determinations disclosed the presence of one *C*-methyl group.

Hydrolysis of griseoviridin with dilute sulphuric acid gives carbon dioxide (0·74 mol.) but very little hydrogen sulphide is liberated.

Experimental

Infrared spectra were determined in " Nujol," unless otherwise stated.

Griseoviridin.—The *compound* separated from pyridine in well-defined plates which, after being dried at 120°/0·1 mm., melted at 228—230° (Found: C, 54·9; H, 5·8; O, 24·4; N, 8·7; S, 6·2; active H, 1·04, 1·11. $C_{22}H_{29}O_7N_3S$ requires C, 55·1; H, 6·1; O, 23·4; N, 8·8; S, 6·7; 5H, 1·04%; *M*, 479·5). Crystallisation from methanol gave large crystals, m. p. 160° (with effervescence), which were dried at 50°/0·1 mm. to give a *hemimethanolate* (Found: C, 54·2; H, 6·3; O, 25·1; N, 8·6; S, 6·0. $C_{22}H_{29}O_7N_3S,0{\cdot}5CH_3{\cdot}OH$ requires C, 54·5; H, 6·3; O, 24·2; N, 8·5; S, 6·5%). On drying at 80°/0·1 mm. it lost weight (2·7%; required 3·2%), giving the anhydrous compound (Found: C, 55·2; H, 6·2; O, 23·0; N, 8·6; S, 6·4%). The dried material did not contain methoxy-groups (Zeisel) and gave only very small and non-reproducible *N*-Me estimations. It showed $[\alpha]_D^{27}$ −237° (0·5% in MeOH). Light absorption: $\lambda_{max.}$ 2205 (ε 44,000), $\lambda_{infl.}$ 2775 Å (ε 1500 in EtOH). Infrared max.: 3300, 1748, 1684, 1645, 1600, 1515, 1412, 1374, 1307, 1276, 1188, 1105, 1083, 1044, 1029, 991, 957, 893, 845, 770, and 759 cm.$^{-1}$.

Molecular weight (by A. J. Durré). With dimethylformamide as solvent at 50°, the Signer method (Clark, *Ind. Eng. Chem. Anal.*, **1941**, **13**, 820) gives a value of 485—490. Similar results were obtained with acetic acid as solvent, but some discoloration occurred.

Unit-cell dimensions and cell molecular weight (by G. W. R. Bartindale). Griseoviridin crystallises from methanol in two forms: form A is obtained above 30° and form B at lower temperatures. Form B loses solvent in air, to give form A (identical *X*-ray powder photographs). The cell dimensions of the monoclinic crystals of form A are: $a = 10{\cdot}72 \pm 0{\cdot}01$, $b = 9{\cdot}58 \pm 0{\cdot}03$, $c = 11{\cdot}705 \pm 0{\cdot}01$, $\beta = 93°\ 33' \pm 3'$. The density (mean of two determinations) is 1·377. The cell molecular weight is, therefore, 995·4 ± 7 units, the unit cell containing $2C_{22}H_{29}O_7N_3S + 1CH_3{\cdot}OH$. There are no systematic absences and the space group is, therefore, *P*2, *Pm*, or *P*2/*m*. Since the analytical data (Found: C, 54·0; H, 6·1%; see also above) indicate that form A is a hemimethanolate, the calculated unit-cell molecular weight would be 991·0.

Test for alcohol groups. Griseoviridin in water gave a light blue colour in 1·5—2 hr. in the chromate–nitric acid test (Fearon and Mitchell, *Analyst*, 1932, **57**, 372) for primary and secondary alcohol groups.

Treatment with periodic acid. The antibiotic (60 mg.) in methanol (10 c.c.) was treated with 1% periodic acid (10·0 c.c.). After 16 hr. excess of periodic acid was titrated (arsenite–iodine method) and it was found that only *ca.* 0·1 mol. of periodate had been consumed.

Griseoviridin diacetate. A suspension of griseoviridin (3·0 g.) in acetic anhydride (25 c.c.) and pyridine (60 c.c.) was left at room temperature for 16 hr. The resulting solution was evaporated to dryness *in vacuo*, xylene (100 c.c.) added, and the mixture re-evaporated similarly. Repeated recrystallisation of the residual solid from methanol–ether–light petroleum (b. p. 40—60°) gave needles of the *diacetate* which after drying at 100°/1 mm. sintered at *ca.* 125° and melted with decomposition at 137—140° (Found, after drying at 100°/1 mm. for 6 hr. : C, 55·4; H, 5·8; N, 7·7; Ac, 14·3, 14·7. $C_{36}H_{33}O_9N_3S$ requires C, 55·4; H, 5·9; N, 7·4; 2Ac, 15·3%). The product showed $[\alpha]_D^{27}$ −230° (0·44 in MeOH); $\lambda_{max.}$ 2180 (ε 41,800) and $\lambda_{infl.}$ 2850 Å (ε 1000 in EtOH); max. at 3378, 1745, 1686, 1650, 1600, 1504, 1372, 1285, 1244, 1209, 1195, 1119, 1065, 1027, 1001, 992, 955, 893, 845, 826, 763, and 725 cm.$^{-1}$.

Treatment of Griseoviridin with Acetic Anhydride–Perchloric Acid.—Griseoviridin (500 mg.), suspended in acetic acid (2·5 c.c.) and acetic anhydride (2·5 c.c.), was treated with 70% perchloric acid (0·2 c.c.); an exothermic reaction occurred and the solid rapidly dissolved. The mixture was kept at 50—55° for 30 min. and the colourless solid (330 mg.) which had separated was collected and washed with a little acetic acid. The *perchlorate diacetate* thus obtained decomposed above 170° without melting (Found : C, 46·6, 46·9; H, 5·2, 5·4; O, 30·8, 31·7; N, 6·3, 6·3; S, 4·7, 4·7; Cl, 5·6, 5·7; Ac, 14·4, 13·5. $C_{36}H_{33}O_9N_3S,HClO_4$ requires C, 47·0; H, 5·2; O, 31·3; N, 6·3; S, 4·8; Cl, 5·3; 2Ac, 13·0%). It showed $[\alpha]_D$ −188° (0·19% in dimethylformamide). Light absorption : $\lambda_{max.}$ 2150 (ε 32,100 in H_2O) : max. at 3663, 3413, 1751, 1672, 1618, 1590, 1513, 1422, 1408, 1339, 1304, 1236, 1176, 1104, 1058, 1035, 1013, 1004, 961, 928, 886, 858, 850, 821, 769, and 745 cm.$^{-1}$. The pK_a value (6·25; equiv., *ca.* 300) was determined by potentiometric titration in 50% methanol.

The same product (identical infrared spectrum) was obtained similarly from griseoviridin diacetate. The perchlorate in ethanol gave no colour with ferric chloride (except on long storage); it dissolved in boiling water, and the cooled solution gave an immediate purple colour with ferric chloride. A purple colour was also obtained by dissolving the solid in sodium hydroxide solution, neutralising the mixture, and adding ferric chloride.

Hydrogenation of Griseoviridin Diacetate.—The diacetate (50·5 mg.) in ethyl acetate (4 c.c.) was hydrogenated in the presence of pre-reduced palladised strontium carbonate (50 mg.; 5% Pd), 5·22 c.c. being absorbed at 20° (calc. for $C_{36}H_{33}O_9N_3S$: 2·16 c.c. per mol. of hydrogen).

In another experiment the diacetate (2·0 g.) in ethyl acetate was hydrogenated in the presence of 5% palladised strontium carbonate (two 3 g. portions) until absorption ceased. Evaporation of the filtered solution followed by repeated recrystallisation from methanol–ether and methanol gave fine needles of *hexahydrogriseoviridin diacetate*, m. p. 213—214° (Found : C, 55·2; H, 7·0; O, 24·8; N, 7·2; S, 5·5. $C_{36}H_{39}O_9N_3S$ requires C, 54·8; H, 6·9; O, 25·3; N, 7·4; S, 5·6%). Infrared max. at 3448, 3344, 3195, 1739, 1692, 1639, 1603, 1592, 1548, 1520, 1330, 1266, 1248, 1229, 1211, 1103, 1071, 1032, 991, 961, 940, 855, 840, 804, and 724 cm.$^{-1}$.

Reaction of Griseoviridin Diacetate with Perbenzoic Acid.—(*a*) The diacetate (641 mg.) in chloroform (75 c.c.) was treated with 0·35M-perbenzoic acid (25 c.c.), aliquot parts being titrated at intervals. Reaction was complete in 24 hr. at 0°, 1·96 mols. of per-acid being consumed : at room temperature 2·14 mols. were consumed and reaction was complete in 7 hr.

(*b*) Chloroformic perbenzoic acid (100 c.c.; 0·34M) was added to the diacetate (3·5 g.) in chloroform (50 c.c.). Next day excess of per-acid was destroyed by addition of citronellol (5 c.c.) and after 20 min. the solution was evaporated *in vacuo*. Repeated extraction with boiling anhydrous ether yielded a colourless amorphous solid (3·1 g.) of indefinite m. p. (135—180° with decomposition). Different runs gave material of varying analysis (C, 48—51%) and attempts to purify the product by recrystallisation failed; these difficulties may be due to reaction with traces of water. The material was, therefore, used directly for hydrolysis.

Treatment of Griseoviridin with Diazomethane.—Griseoviridin (650 mg.) in methanol (30 c.c.) was treated with excess of diazomethane and after 3 hr. the remaining diazomethane was destroyed with acetic acid. Evaporation yielded a gum from which some griseoviridin was recovered by trituration with acetone. The mother-liquors were evaporated and the yellow residue dissolved in a little methanol; this solution slowly deposited crystalline material (100 mg., m. p. 220—240°). Repeated recrystallisation from methanol yielded plates of a *compound*,

m. p. 262—264° (decomp.) (Found : C, 56·4; H, 6·0; O, 22·7; N, 8·5; S, 6·6; *C*-Me, 5·8; OMe, 0. $C_{23}H_{31}O_7N_3S$ requires C, 56·0; H, 6·3; O, 22·7; N, 8·6; S, 6·5; 2 *C*-Me, 6·1%). No ionisable groups could be detected in the range pH 3·2—12·4 by potentiometric titration in 50% aqueous dimethylacetamide. Light absorption : $\lambda_{max.}$ 2700 (ε 2800) and $\varepsilon_{infl.}$ 2210 Å (ε 46,000) in EtOH; infrared max. at 3425, 1730, 1698, 1642, 1592, 1511, 1412, 1370, 1326, 1307, 1221, 1189, 1101, 1066, 1050, 990, 843, 829, and 761 cm.$^{-1}$.

Alkaline Hydrolyses.—(*a*) Griseoviridin (125 mg.) was boiled with 0·5N-barium hydroxide solution (25 c.c.) in a stream of nitrogen; ammonia (0·92 mol.) was evolved during 50 min. In similar experiments the perbenzoic acid oxidation product and hexahydrogriseoviridin diacetate also gave ammonia (0·90 and 1·03 mol. respectively). In another experiment griseoviridin (108 mg.) was boiled with sodium hydroxide solution, and the ammonia produced was identified by reaction with phenyl *iso*thiocyanate : the derivative had m. p. and mixed m. p. 150—152°. The alkaline solution was acidified with sulphuric acid and steam-distilled, hydrogen sulphide being evolved. The distillate was basified and evaporated to dryness *in vacuo*. The resulting sodium salt was converted into the hydroxamic acid, and the latter identified as acethydroxamic acid by paper chromatography following Thomson's procedure (*Austral. J. Sci. Res.*, 1951, **4**, *B*, 180). Acetic acid is thus formed during the hydrolysis.

(*b*) A hydrolysate obtained similarly was acidified after 50 minutes' boiling and the evolved hydrogen sulphide estimated as lead sulphide. The yield corresponded to 1·86% of sulphur, *i.e.*, about a third of that present in the antibiotic. Sodium sulphide is apparently not present in the alkaline hydrolysate because only a trace of brown precipitate was formed on the addition of alkaline lead acetate solution.

(*c*) Griseoviridin (145 mg.) was refluxed for 1 hr. with 25 c.c. of 0·1N-sodium hydroxide. Titration with standard acid showed that acid groups had been generated during the hydrolysis (sap. equiv. : 182). Similar results were obtained after 3 hours' refluxing (equiv., 169) or after 1 hour's boiling with N-alkali (equiv., 180). More standard acid was then added to each hydrolysate so that the total was exactly equivalent to the alkali taken (*i.e.*, the organic acids were liberated from the sodium salts). Next day the solutions were re-titrated with alkali (phenolphthalein indicator) but less alkali was now required (equiv., 285, 295). It therefore appears that three titratable acid groups are generated by alkaline hydrolysis but one of these recombines slowly in faintly acid solution.

(*d*) A suspension of griseoviridin (*ca.* 100 mg.) in 0·1N-sodium hydroxide (25 c.c.) was shaken at room temperature until all the solid had dissolved (24 hr.) and then for a further 24 hr. Titration with acid showed that two acid groups had been liberated (sap. equiv., 308, 284, 312). Addition of the calculated quantity of acid as in (*c*) and re-titration with alkali after 24 hr. gave equiv., 470, 494. Again one of the acid groups has apparently recombined. The cold alkaline hydrolysate did not smell of ammonia.

Acidic Hydrolyses.—(*a*) When griseoviridin (56·6 mg.) was boiled with 2N-sulphuric acid (20 c.c.), carbon dioxide was liberated (0·74 mol. in 2 hr.), much tar being formed. Only a trace of hydrogen sulphide was evolved under these conditions.

(*b*) A sample (116 mg.) of griseoviridin was refluxed with 0·1N-sulphuric acid (25 c.c.) in a stream of nitrogen for 15 min. (dissolution required 5 min.). The solution remained colourless and only a trace of hydrogen sulphide was evolved; no volatile aldehyde or ketone was produced. Titration of the solution with standard alkali showed the formation of 0·88 mol. of acid.

(*c*) The solution obtained by boiling griseoviridin (58 mg.) with 5N-sulphuric acid (20 c.c.) for 1 hr. in nitrogen was steam-distilled. Acetic acid was identified in the distillate by the procedure already described.

Acetyl Value and C-Methyl Determinations (by A. J. Durré).—Wiesenberger's procedure (*Mikrochem. Mikrochim. Acta*, 1948, **33**, 51) was used. Preliminary experiments with 12N-sulphuric acid for hydrolysis of glucose penta-acetate gave acetyl values in the range 5—5·5 groups. Under similar conditions glucose also gave an " acetyl value " of *ca.* 0·5 group. Satisfactory results were obtained, however, when both compounds were hydrolysed with *ca.* 7N-sulphuric acid for ½ hr. When griseoviridin was hydrolysed similarly the observed acetyl value was 0·22% ($C_{23}H_{29}O_7N_3S$ requires 1Ac, 9·0%). More prolonged hydrolysis (1—5 hr.) gave values of *ca.* 0·5%.

In view of these results Kuhn–Roth determinations were also carried out in *ca.* 7N-sulphuric acid (Found : *C*-Me, 2·9, 2·7, 2·5. $C_{23}H_{29}O_7N_3S$ requires *C*-Me, 3·1%).

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*Griseoviridin. Part II.**

By D. E. Ames and R. E. Bowman.

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Experiments on the desulphurisation, acid hydrolysis, and ozonolysis of griseoviridin and its derivatives are described and partial structures are proposed for two groupings in the molecule.

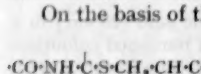
It was shown in Part I* that hydrogenation of acetylated griseoviridin in presence of palladium catalysts fails to attack at least one of the chromophoric systems present. Desulphurisation of griseoviridin with Raney nickel, however, yielded a small amount of a crystalline product, probably $C_{22}H_{39}O_7N_3$, which exhibited no selective light absorption above 2100 Å; like griseoviridin it contained no ionisable groups. Similarly desulphurisation of griseoviridin diacetate gave, in higher yield, a crystalline product, which appears to be a diacetyl derivative of the compound obtained from griseoviridin itself. These products are provisionally named octahydrodethiogriseoviridin and its diacetate. The evidence previously obtained together with the fact that no oxygen atoms are removed during desulphurisation, indicate that griseoviridin probably contains a cyclic sulphide group. No ammonia was liberated on alkaline hydrolysis of the desulphurisation product. Hydrolysis with hydrochloric acid furnished less than one mol. of D-α-alanine but, although two α-amino-acid groups were shown to be present (Van Slyke method), no other amino-acid could be isolated.

Similar hydrolytic experiments with griseoviridin showed that only one α-amino-acid group was liberated; cystine and a much smaller amount of serine were detected by paper chromatography. The product obtained from griseoviridin diacetate and perbenzoic acid also gave cystine on hydrolysis, the amino-acid being identified by paper chromatography; this result confirms that the sulphide group has not been oxidised.

Treatment of a griseoviridin acid-hydrolysate with Brady's reagent gave a small quantity of a dinitrophenylhydrazone, probably $C_{14}H_{14}O_7N_4$, which did not contain any acidic groups. Presumably the high oxygen content is due to hydroxyl or free carbonyl groups. The absorption ($\lambda_{max.}$ 3560 Å) showed that there is no unsaturated system in conjunction with the dinitrophenylhydrazone residue. Attempts to prepare a dinitrophenylhydrazone from griseoviridin have so far been unsuccessful and so it appears that this ketone arises from a masked carbonyl group in the antibiotic.

Reduction of griseoviridin with red phosphorus and hydriodic acid gave D-cystine and α-alanine as the only recognisable products.

On the basis of the above evidence it is suggested that griseoviridin contains the system (I) which is hydrolysed by acid to give mainly ammonia, a keto-acid, and cysteine. This would account for a number of observations. First, ammonia is obtained from griseoviridin but not from the desulphurisation product on alkaline hydrolysis. Secondly, the formation of some serine and hydrogen sulphide would be expected if cleavage first occurs to a minor extent at the S–CH_2 bond during acid hydrolysis. Thirdly, in the alkaline hydrolysis of griseoviridin the initial attack would be expected to occur at the S–CH_2 bond, rather than at the acetal-type group ·NH·C·S·, and to lead to the formation of ammonia and thioketone; this would explain why hydrogen sulphide is liberated on acidification although little or no sodium sulphide is present in the hydrolysate (see Part I). Fourthly, the desulphurisation products would then contain two α-amino-acid residues compared to the one of griseoviridin, as observed. Finally, this is consistent with the fact that griseoviridin contains one *C*-methyl group whereas octahydrodethiogriseoviridin contains two such groups.

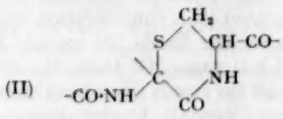


(I)

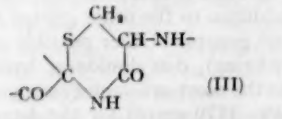
If the system (I) formulated above is indeed present in griseoviridin it must be in the form of a ring, probably (II) or (III), for fission of the molecule does not occur on desulphurisation.

* Part I, preceding paper.

Griseoviridin, although neutral and practically insoluble in water, dissolves rapidly in cold concentrated hydrochloric acid. The light absorption shown by the solution ($\lambda_{max.}$ 2160 Å, $E^{1\%}_{1cm.}$ *ca.* 500) is much less intense than that of griseoviridin in organic solvents, indicating that a chromophore has been destroyed by hydrolysis. A well-defined,



(II)



(III)

crystalline hydrochloride, isolated from the hydrolysate, could be recrystallised but decomposed without melting. Analytical data on three different specimens were concordant but corresponded to the composition, $C_{22}H_{29}O_7N_3S,1{\cdot}09HCl$. Potentiometric titration with alkali disclosed the presence of two titratable groups (pK_a 6·5), one of which is evidently the amine hydrochloride. On back-titration, however, only one titratable group, of similar pK_a value, could be detected (the titration of this single group was then reproduced on re-titration). Clearly one of the functional groups, probably the amine, has been irreversibly removed by neutralisation. Catalytic hydrogenation of the hydrochloride furnished a small amount of a crystalline product of uncertain formula. With alkali and *p*-phenylphenacyl bromide the hydrochloride gave a derivative, $C_{35}H_{37}O_8N_3S$. Neither of these compounds contained any titratable groups.

Ozonolysis studies on griseoviridin and various derivatives have been carried out, the diacetate being used first owing to its greater solubility. Distillation of the reaction mixture with very dilute sulphuric acid, water, or sodium carbonate solution yielded crotonaldehyde, isolated as the dinitrophenylhydrazone. The residual solution also gave a precipitate with Brady's reagent but no crystalline product could be isolated. Crotonaldehyde was obtained in high yield, even when the solution was thoroughly saturated with ozone, and therefore appears to be an artifact. When the solution after treatment with ozone was immediately added to Brady's reagent and the precipitate examined by paper chromatography, no crotonaldehyde or aldol derivative could be detected.

Griseoviridin also gave crotonaldehyde when treated similarly or when subjected to alkaline hydrolysis followed by ozonolysis. The crystalline hydrochloride again gave crotonaldehyde but, in this case, paper chromatography indicated the presence of the crotonaldehyde, aldol, and acetaldehyde derivatives in the product. This evidence is regarded as an indication of the presence of the system $CH_3{\cdot}CH(OH){\cdot}CH_2{\cdot}CH{:}C<$ in the hydrochloride and of the group $CH_3{\cdot}CH(O–){\cdot}CH_2{\cdot}CH{:}C<$ in griseoviridin. The oxygen atom in this system must be part of an acid-labile grouping such as an enol-ether or acetal. Hexahydrogriseoviridin diacetate gave no crotonaldehyde on ozonolysis followed by acid hydrolysis, and therefore the double bond in the above system is one of those reduced during the hydrogenation.

The epoxy-acetate (Part I) also yielded crotonaldehyde on ozonolysis and hydrolysis. It was unexpectedly found that crotonaldehyde was produced by acid hydrolysis of the epoxy-acetate; glyoxal was also identified in this hydrolysate. The grouping $CH_3{\cdot}CH(O–){\cdot}CH_2{\cdot}CH{:}N{\cdot}CO–$ would provide a possible explanation of the hydrolysis of the epoxy-acetate but the following evidence leads us to eliminate this. Since griseoviridin is non-basic the nitrogen atom would then be that evolved as ammonia on hydrolysis. Hydrogenation of the acetate, however, has been shown above to involve reduction of the double bond in the potential crotonaldehyde residue and this is incompatible with the observed liberation of ammonia on hydrolysis of hexahydrogriseoviridin diacetate. It therefore appears that another explanation of these observations must be sought and only the presence of the system $CH_3{\cdot}CH(·O–){\cdot}CH_2CH{:}C<$ in griseoviridin can be proposed now.

Finally there are the infrared spectra of griseoviridin and its derivatives. In the Table the bands in the region 3500—1500 cm.$^{-1}$ are grouped arbitrarily for convenience. All the compounds show a band (B) in the range 1730—1761 cm.$^{-1}$ which in the acetylated derivatives must be due, at least in part, to the acetoxy-groups. If griseoviridin itself

contained a difficultly hydrolysed acetoxy-group this would account for all the bands (B) but the results of acetyl-value determinations (Part I) and the following considerations lead us to regard this as unlikely. First, griseoviridin and also derivatives **4**, **6**, **7**, **8**, and **9** do not show intense absorption bands near **1250** cm.$^{-1}$, a characteristic frequency of acetates. Secondly, there are too few oxygen atoms present to account for an acetoxy-group in addition to the other groups already indicated (this consideration applies equally to a lactone group). Other possible assignments for the bands (B) include ketone (in a 5-membered ring), diacylimide or hydantoin, and β-lactam. Of these the diacylimide is regarded as the most satisfactory assignment since all the bands (B) fall within the expected range (**1718—1779** cm.$^{-1}$) for the **4**-carbonyl group (Randall, Fowler, Fuson, and Dangl, " Infra-red Determination of Organic Structures," Van Nostrand, 1949, p. 20). Further, all the compounds except **5** show a band (C) in the range (**1656—1712** cm.$^{-1}$) characteristic of the 2-carbonyl group of diacylimides (*op. cit.*). The compounds all exhibit at least one band (D) in the range **1600—1669** cm.$^{-1}$, and another (E) at 1500—1565 cm.$^{-1}$ as expected for amide groups.

Infrared absorption spectra in 3500—1500 *cm.*$^{-1}$ *region.*

	A	B	C	D	E
1. Griseoviridin	3300	1748	1684	1645	1515
				1600	
Griseoviridin *	3425	1739	1681	1597	—
2. Griseoviridin diacetate	3378	1745	1686	1650	1504
				1600	
3. Hexahydrogriseoviridin diacetate	3448	1739	1692	1639	1548
	3344			1603	1520
	3195			1592	
4. Octahydrodethiogriseoviridin	3460	1761	1669	1650	1567
	3367				1548
	3155				
5. Diacetate of no. 4	3390	1739	—	1647	1562
6. Hydrochloride	3378	1748	1667	1616	1585
					1520
7. Hydrogenation product from no. 6	3521	1739	1675	1592	1527
	3185				1511
8. *p*-Phenylphenacyl derivative of no. 6	3425	1739	1701	1645	1504
			1675	1631	
				1610	
9. Product from diazomethane and griseoviridin	3425	1730	1698	1642	1511
				1592	
10. Epoxy-acetate	3472	1751	1684	1605	1517
11. Perchlorate diacetate	3663	1751	1672	1618	1513
	3413			1590	

* Saturated solution in tetrahydrofuran. Others in " Nujol " mulls.

Experimental

Desulphurisation of Griseoviridin.—Griseoviridin (3·75 g.) in ethanol was hydrogenated in the presence of Raney nickel (several portions added at intervals). The filtered solution was concentrated to 150 c.c., refluxed for 3 hr. with more catalyst, filtered again, and evaporated to dryness *in vacuo*. Repeated recrystallisation of the residue from methanol–ethyl methyl ketone gave fine needles of *octahydrodethiogriseoviridin*, m. p. 190—192°, $[\alpha]_D^{20}$ −32° (0·5% in MeOH) (Found : C, 57·4, 57·7; H, 8·4, 8·7; O, 24·9; N, 9·1, 9·1; S, 0; *C*-Me, 5·3; Ac, 0. $C_{22}H_{39}O_7N_3$ requires C, 57·8; H, 8·6; O, 24·5; N, 9·2; 2*C*-Me, 6·6%). The yield of crude material, m. p. 160—168°, was 0·68 g. Potentiometric titration in 50% aqueous methanol revealed the absence of titratable groups in the range, pH 2—11. Infrared max. at 3460, 3367, 3155, 1761, 1669, 1650, 1567, 1548, 1353, 1337, 1259, 1226, 1177, 1133, 1115, 1089, 1055, 1048, 1015, 980, 971, 958, 935, 926, 902, 877, 855, and 830 cm.$^{-1}$.

Desulphurisation of Griseoviridin Diacetate.—Raney nickel catalyst, prepared at 0—10° from the alloy (200 g.), was washed until neutral in the usual manner and then left overnight with water (1 l.) containing acetic acid (10 c.c.). The catalyst was finally washed with water, ethanol (95%; 3 × 1 l.) and ethyl acetate (3 × 600 c.c.).

Griseoviridin diacetate (7·0 g.) in ethyl acetate was hydrogenated at a palladised strontium carbonate catalyst (5% Pd); the filtered solution was diluted to 1·5 l. with ethyl acetate and

refluxed for 2·5 hr. with the Raney nickel. The hot solution was filtered and concentrated to small volume at atmospheric pressure. After the mass had been left to crystallise, it was dried *in vacuo* to give 5·1 g. of material which softened at 140° and melted at 175—180°. Repeated recrystallisation from ethyl acetate–light petroleum (b. p. 60—80°) containing a little acetic anhydride gave *octahydrodethiogriseoviridin diacetate* as needles, m. p. 213—215°, $[\alpha]_D^{27}$ −34° (0·16% in MeOH) (Found: C, 57·6, 58·1, 58·1; H, 7·6, 7·8, 7·7; O, 27·0, 26·5, 26·4; N, 7·9, 7·7, 7·7; S, 0; Ac, 14·6. $C_{24}H_{43}O_9N_3$ requires C, 57·7; H, 8·0; O, 26·6; N, 7·8; 2Ac, 15·9%). No titratable groups were detected by potentiometric titration. No ultraviolet max. above 2100 Å (ε 3100 at 2100 Å); infrared max. at 3268, 3204, 3112, 2536, 1735, 1640, 1557, 1305, 1268, 1235, 1213, 1176, 1158, 1132, 1115, 1060, 1046, 1028, 979, 958, and 935 cm.$^{-1}$.

The same product (m. p. and mixed m.p.) was obtained by similar desulphurisation of the acetate without preliminary hydrogenation.

Examination of Octahydrodethiogriseoviridin Diacetate.—(a) *Alkaline hydrolysis.* No ammonia was evolved when the compound (81 mg.) was refluxed with N-sodium hydroxide (25 c.c.) in a slow stream of nitrogen, the solution remaining colourless. Attempts to isolate recognisable or crystalline products from the hydrolysate were unsuccessful.

(b) *Acid hydrolysis.* (i) (With A. J. Durré.) The compound was boiled with 6N-hydrochloric acid for 20·5 hr. and α-amino-acid groups estimated by the method of Van Slyke, MacFadyen, and Hamilton (*J. Biol. Chem.*, 1941, **141**, 671) (2·08 groups found).

(ii) The substance (0·5 g.) was refluxed with 6N-hydrochloric acid (20 c.c.) for 15 hr. and the solution evaporated *in vacuo*; the residue in water gave no precipitate with Brady's reagent. Treatment of the solution with ninhydrin (200 mg.) and citrate buffer mixture gave volatile aldehyde, isolated as the 2 : 4-dinitrophenylhydrazone. The derivative was identified as that of acetaldehyde by paper chromatography [upper phase of methanol–light petroleum (b. p. 100—120°)]; recrystallisation gave acetaldehyde 2 : 4-dinitrophenylhydrazone, m. p. and mixed m. p. 155—157°.

(iii) Hydrolysis of the diacetate (1 g.) was carried out similarly and the residue, on evaporation, taken up in water and examined by paper chromatography with butanol–water–acetic acid (4 : 5 : 1), the spots being detected with ninhydrin. Three spots (R_F 0·3, 0·6, and 0·8) of approximately equal intensity were obtained, the first corresponding to alanine. The hydrolysate was subjected to counter-current extraction with the same solvent mixture (13 × 10 c.c. of lower phase, 24 × 15 c.c. of upper phase). The three ninhydrin-sensitive components were well resolved but the other two showed a spectacular loss in intensity compared with the alanine; presumably those components are unstable when liberated from the hydrochlorides.

In another experiment, the diacetate (2·7 g.) was refluxed with concentrated hydrochloric acid (40 c.c.) for 20 hr. and the dark brown solution diluted with water (250 c.c.), filtered (charcoal), and applied to a column of Amberlite resin IR-120(H). After the column had been washed with water, the bases were eluted with 6N-ammonia until the eluate no longer gave a ninhydrin reaction. Evaporation yielded a gum (1·2 g.) containing some solid; this mixture was subjected to counter-current extraction as before. The first eight lower phases contained almost all the alanine (R_F 0·30), 0·22 g. being obtained be evaporation. Recrystallisation from aqueous ethanol (charcoal) gave D-α-alanine, $[\alpha]_D^{19}$ −13·4° (0·825 g. in 2·0 c.c. of N-HCl) (Found: C, 39·9; H, 7·9. Calc. for $C_3H_7O_2N$: C, 40·4; H, 7·9%). The identification was confirmed by degradation with ninhydrin to acetaldehyde (m. p. and mixed m. p. of dinitrophenylhydrazone). Repeated attempts to isolate crystalline products from the other fractions from the counter-current extraction were unsuccessful.

Acid Hydrolysis of Griseoviridin.—(*a*) (With A. J. Durré.) Griseoviridin was hydrolysed with 6N-hydrochloric acid, and α-amino-acid groups were estimated by the method of Van Slyke, MacFadyen and Hamilton (*loc. cit.*) and liberated ammonia by that of Conway ("Microdiffusion Analysis and Volumetric Error," Crosby Lockwood, 3rd. edn., 1950). Complete hydrolysis appeared to require *ca.* 22 hours' boiling; 0·87 α-amino-acid group was produced and 0·78 mol. of ammonia liberated, but considerable formation of tar also occurred. When griseoviridin was refluxed with 2N-sulphuric acid until dissolution was complete (20 min.), only 0·02 α-amino-acid group was produced.

(*b*) The hydrolysate obtained by refluxing griseoviridin (0·5 g.) with 6N-hydrochloric acid for 3 hr. was evaporated *in vacuo* and the residue taken up in water (100 c.c.). After addition of citric acid–sodium citrate buffer and ninhydrin (100 mg.), the solution was distilled but the distillate gave no precipitate with Brady's reagent, indicating the absence of alanine in the hydrolysate.

(*c*) A similar hydrolysate was filtered (charcoal) and treated with 2 : 4-dinitrophenylhydrazine

in 2N-hydrochloric acid. A brown solid separated slowly and after a week it was collected (centrifuge). Repeated recrystallisation from methanol (charcoal) furnished a small quantity of a *dinitrophenylhydrazone*, which formed orange needles, m. p. 220—222° (slight decomp.) (Found : C, 47·6; H, 3·7; N, 16·1. $C_{14}H_{14}O_7N_4$ requires C, 48·0; H, 4·0; N, 16·0%). No acidic groups could be detected by potentiometric titration. Light absorption : $\lambda_{max.}$ 3560 ($E^{1\%}_{1\ cm.}$ 730), $\lambda_{infl.}$ 2500 Å ($E^{1\%}_{1\ cm.}$ 350); max. at 3135, 3080, 1687, 1679, 1615, 1594, 1414, 1348, 1303, 1289, 1258, 1215, 1202, 1166, 1158, 1137, 1109, 1088, 1057, 1044, 959, 945, 922, 918, 854, 832, 774, and 765 cm.$^{-1}$.

(*d*) Griseoviridin (100 mg.) was dissolved in cold concentrated hydrochloric acid (5 c.c.) and, after addition of water (5 c.c.), the solution was refluxed for 6 hr. (bath 150°). The dark brown hydrolysate was filtered (charcoal) and examined by paper chromatography. On application of Boissonas's two-dimensional method (*Helv. Chim. Acta*, 1950, **33**, 1966) with phenol–water (7 : 3) and then propan-1-ol–water (7 : 3) two well-defined spots were obtained. The first, near the origin, corresponded to cystine while the second (R_F 0·24 and 0·33 for the two solvent mixtures) corresponded to serine when authentic amples were run simultaneously. On a one-dimensional paper chromatogram (butan-1-ol–water–acetic acid, 4 : 5 : 1, upper phase) the hydrolysate gave a bluish-brown streak on development with ninhydrin but three purple spots were observed : (i) R_F 0·37, unidentified; (ii) R_F 0·16, serine; and (iii) R_F 0·06, cystine. In both chromatograms the cystine spot was very much more intense than that of serine; in the second chromatogram the third spot was also much less intense than that of cystine. To ensure that the serine did not arise from the hydrolysis of cysteine or cystine a mixture of these was similarly treated with hydrochloric acid but no serine could be detected by paper chromatography.

Reduction of Griseoviridin with Phosphorus–Hydriodic Acid.—A mixture of griseoviridin (2·0 g.), red phosphorus (0·5 g.), and hydriodic acid (30 c.c.; *d* 1·7) was refluxed (bath 150°) for 5 hr. and filtered, the solid being washed with water. The combined solutions were concentrated to small volume under reduced pressure and the residual gum was taken up in water and applied to a column of Amberlite ion-exchange resin IRA-400(OH). The column was washed with water until the effluent was neutral. Elution of the column with 10% acetic acid (1 l.) and evaporation of the eluate furnished a gum which partially crystallised. Trituration with water yielded cystine (90 mg.) which was recrystallised from water (Found : C, 30·0; H, 5·3; N, 11·1. Calc. for $C_6H_{12}O_4N_2S_2$: C, 30·0; H, 5·0; N, 11·7%). It was identified by paper chromatography (butan-1-ol–water–acetic acid, 4 : 5 : 1) and by the identity of the infrared spectrum with that of an authentic sample; it also gave a purple colour with sodium cyanide followed by sodium nitroprusside solutions. The optical rotation ($[\alpha]_D^{22\cdot6}$ +218° in N-HCl) showed that it was the D-isomer.

The mother-liquor from which cystine had been separated was evaporated to dryness and subjected to counter-current distribution with butan-1-ol–water–acetic acid (4 : 5 : 1; 13 × 10 c.c. of lower phase and 36 × 15 c.c. of upper phase). Cystine (R_F 0·09 in same solvent mixture) was present in the first five lower phases, and alanine (R_F 0·24) in the remainder. Alanine (0·2 g.), isolated by evaporation and crystallisation of the residue from aqueous alcohol, was identified by its infrared spectrum; this sample had been almost completely racemised ($[\alpha]_D^{25}$ −0·6° in N-HCl).

Reaction of Griseoviridin with Cold Concentrated Hydrochloric Acid.—(*a*) (With Miss E. M. Tanner.) Griseoviridin dissolves very rapidly in cold concentrated hydrochloric acid. Portions of the solution were diluted with water, after a given time, for light absorption measurements :

Freshly prepared solution	$\lambda_{max.}$	2160 Å,	$E^{1\%}_{1\ cm.}$	588;	$\lambda_{infl.}$	2850 Å;	$E^{1\%}_{1\ cm.}$ 50
After 20 min.	,,	2120	,,	545	,,	2850	,, 39
After 2 days	,,	2160	,,	497	,,	—	,, —

(*b*) Griseoviridin (3·0 g.) was dissolved in concentrated hydrochloric acid (30 c.c.), and the colourless solution evaporated to dryness *in vacuo* (bath 20—30°). On addition of acetone (20 c.c.) and a few drops of methanol crystallisation began and, after 30 minutes' shaking, the colourless crystals (2·1 g.) were separated and washed with a small volume of acetone. Recrystallisation from ether–methanol furnished well-defined needles of a *hydrochloride* which decomposed without melting below 300°. Inserted in a bath preheated to 150°, however, it melted with much decomposition at *ca.* 180°. Analytical results on different batches of this material were reproducible, and unchanged by further recrystallisation, but the Cl : N : S ratio indicated the presence of more than 1 mol. of hydrogen chloride (Found, on material dried at

20°/ or 50°/0·5 mm. : C, 51·5, 51·2, 51·2; H, 5·9, 5·6, 5·6; O, 21·4; N, 8·0, 8·1; Cl, 7·4, 7·4; S, 5·9, 5·7. $C_{22}H_{29}O_7N_3S$,1·09HCl requires C, 5·09; H, 5·8; O, 21·6; N, 8·1; Cl, 7·4; S, 6·2%).

(*c*) (With Miss E. M. TANNER.) In potentiometric titration of the hydrochloride in water two mols. of alkali were required (equiv., 270. Calc. for $C_{22}H_{29}O_7N_3S$,1·09HCl: 519) but on back-titration of this solution only one mol. of acid is consumed (equiv., 540). Subsequent re-titration also requires only one mol. of alkali (equiv., 540). Neutralisation to pH 7 suffices to effect this change.

Hydrogenation of Hydrochloride.—Palladised charcoal (3 g., 10% Pd) was pre-reduced under 95% ethanol (70 c.c.), and the hydrochloride (1·0 g.) added. Absorption of hydrogen ceased when about 3 mols. had been taken up in 4 hr. The filtered solution was evaporated *in vacuo*; the residual glass dissolved in methanol and, on being left at 0° overnight, the solution deposited crystals (0·15 g.), m. p. 232—236°. The pure product separated from methanol in fine, prismatic needles, m. p. 247—248° (Found : C, 55·6; H, 6·9; O, 22·0; N, 8·8; S, 6·4. $C_{22}H_{33}O_7N_3S$ requires C, 55·5; H, 7·1; O, 22·5; N, 8·5; S, 6·4. $C_{21}H_{33}O_6N_3S$ requires C, 55·3; H, 7·3; O, 21·1; N, 9·2; S, 7·0%). Although the analytical sample was dried at 50° in a high vacuum, the substance might possibly contain methanol of crystallisation. No titratable groups were detected by potentiometric titration. Light absorption : no maximum above 2150 Å ($E^{1\%}_{1\,cm.}$ 380 at 2150 Å); max. at 3521, 1739, 1675, 1592, 1527, 1511, 1359, 1328, 1196, 1104, 1053, 979, 909, 860, 840, 766, and 725 cm.$^{-1}$.

Condensation of Hydrochloride with p-*Phenylphenacyl Bromide.*—A suspension of the hydrochloride (0·5 g.) in 95% ethanol was titrated with sodium hydroxide solution (2·0 c.c. of N required) with phenolphthalein as indicator. *p*-Phenylphenacyl bromide (0·30 g.) was added and the solution refluxed for 30 min. After 48 hr. a hard crystalline mass had separated from the solution. Recrystallisation from chloroform–ethanol furnished fine needles of a *derivative*, m. p. 288—289° (Found : C, 63·3; H, 5·5; O, 20·1; N, 6·3; S, 4·4. $C_{35}H_{37}O_6N_3S$ requires C, 63·7; H, 5·7; O, 19·4; N, 6·4; S, 4·8%).

Ozonolysis of Griseoviridin Diacetate.—(*a*) The diacetate (0·35 g.) in glacial acetic acid (25 c.c.) was saturated with ozonised oxygen, and excess of ozone then swept away by a stream of oxygen. The solution was poured into water (100 c.c.) containing sulphuric acid (0·2 c.c. of 2N) and distilled. Treatment of the distillate with Brady's reagent gave crotonaldehyde 2 : 4-dinitrophenylhydrazone (75% yield), fine red needles (from methanol), m. p. and mixed m. p. 184—186° (Found : C, 47·6; H, 4·1; O, 25·0; N, 22·9. Calc. for $C_{10}H_{10}O_4N_4$: C, 48·0; H, 4·0; O, 25·6; N, 22·4%). The identity of this product was confirmed by comparison of the infrared and ultraviolet absorption spectra and by paper chromatography [methanol–light petroleum (b. p. 100—120°)], both samples giving a single spot, of R_F 0·50.

Treatment of the distillation residue with Brady's reagent gave a yellow precipitate (0·23 g.) but this decomposed without melting and attempts to isolate a crystalline product were unsuccessful.

(*b*) In another experiment, the acetic acid solution was ozonised and then treated with zinc dust. After 10 min., the filtered solution was treated with Brady's reagent; the resulting yellow precipitate softened above 50° but gradually decomposed at 150—230° without completely melting. When examined by paper chromatography, as in (*a*), this material showed R_F <0·07 indicating the absence of the derivatives of both crotonaldehyde and aldol.

Ozonolysis of Griseoviridin.—When griseoviridin in acetic acid was ozonised the results were similar to those obtained with the acetate. No crotonaldehyde or aldol dinitrophenylhydrazone could be detected when the solution was treated directly with Brady's reagent but the crotonaldehyde derivative was obtained in 80% yield after boiling with water. When the ozonised solution was basified with sodium carbonate solution and distilled, crotonaldehyde dinitrophenylhydrazone was isolated in 56% yield.

Miscellaneous Ozonolysis.—(*a*) The crystalline hydrochloride (80 mg.) in water (15 c.c.) was treated with ozonised oxygen for 25 min. and the solution poured immediately into Brady's reagent. The precipitate, examined by paper chromatography as before, contained the derivatives of crotonaldehyde and, in smaller amounts, acetaldehyde (R_F 0·39) and aldol (R_F 0·10). Similar results were obtained by ozonolysis of the hydrochloride dissolved in 0·1N-sodium hydroxide.

(*b*) Hexahydrogriseoviridin diacetate, ozonised in acetic acid, gave no crotonaldehyde even on distillation of the mixture with dilute sulphuric acid.

(*c*) The epoxy-acetate (Part I) was ozonised similarly; no crotonaldehyde could be obtained by treating the solution with Brady's reagent until after it had been boiled with water.

(*d*) Griseoviridin (200 mg.) was boiled with 0·1N-sodium hydroxide solution for 30 min. and

the resulting solution treated with ozonised oxygen for 30 min. Steam-distillation and addition of Brady's reagent to the distillate yielded a crystalline dinitrophenylhydrazone. Spots corresponding to the crotonaldehyde and acetaldehyde derivatives were obtained by paper chromatography, the latter spot being much the less intense.

Hydrolysis of Griseoviridin Epoxy-acetate.—(*a*) The crude epoxide (50 mg.; Part I) was distilled with 0·02N-sulphuric acid (100 c.c.) and the distillate treated with Brady's reagent. The precipitated dinitrophenylhydrazone was homogeneous and was identified as the crotonaldehyde derivative by paper chromatography (cf. above). A similar experiment on griseoviridin gave no aldehyde in the distillate.

(*b*) The epoxide (320 mg.) was refluxed for 4 hr. with 6N-hydrochloric acid (15 c.c.). After addition of water (65 c.c.), the solution was distilled (30 c.c. removed) and the residue treated with Brady's reagent. A dark red solid which had separated after 20 hr. was collected (centrifuge) and recrystallised by addition of ethanol to a filtered (charcoal) solution in pyridine. The product was identified as glyoxal bisdinitrophenylhydrazone by comparison of the infrared spectrum with that of an authentic sample. It also showed the expected ultraviolet light absorption ($\lambda_{max.}$ 4600 Å) and gave a deep blue colour with aqueous-methanolic sodium hydroxide.

(*c*) In a similar experiment the hydrolysate was examined by two-dimensional paper chromatography (7 : 3 phenol–water, followed by 7 : 3 propan-1-ol–water). Development with ninhydrin revealed an intense spot near the origin corresponding to cystine but there were no other spots of comparable intensity. Paper chromatography, with butanol–water–acetic acid (4 : 5 : 1), gave two spots, of R_F 0·12 (faint, serine) and R_F 0·05 (intense, cystine) identical with those given by a griseoviridin hydrolysate run simultaneously.

Permanganate Oxidation of Griseoviridin.—A hydrolysate prepared by refluxing griseoviridin (350 mg.) with 0·1N-sodium hydroxide (20 c.c.) for 25 min. was cooled at 30—40° while barium permanganate (1·8 g.) in water (40 c.c.) was added during 10 min. After 15 min. excess of permanganate was destroyed by addition of sodium nitrite and the filtered solution was concentrated to small volume. The distillate gave a small quantity of precipitate with Brady's reagent, and this was examined by paper chromatography [methanol–light petroleum (b. p. 100—120°)]. Three spots were obtained (R_F 0·49, 0·30, and 0·28) corresponding to the crotonaldehyde, acetaldehyde, and formaldehyde derivatives. Another spot (intense blue with alkali spray) did not move from the origin.

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Chemistry of the Higher Fungi. Part V. The Structures of Nemotinic Acid and Nemotin.*

By J. D. Bu'Lock, E. R. H. Jones, and P. R. Leeming.

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The antibiotics nemotinic acid and nemotin have been separated from closely similar compounds produced by the same fungus and, despite their instability, have been characterised. Their high optical activity is due to the presence of asymmetrically substituted allenic groups. Nemotinic acid is readily converted into nemotin; the two compounds are shown to be 4-hydroxyundeca-5 : 6-diene-8 : 10-diynoic acid and the corresponding lactone.

In 1950, workers at the New York Botanical Gardens (Anchel, Polatnick, and Kavanagh, *Arch. Biochem.*, 1950, **25**, 208; Kavanagh, Hervey, and Robbins, *Proc. Nat. Acad. Sci. U.S.A.*, 1950, **36**, 1) reported the isolation, from cultures of an unidentified Basidiomycete and also from *Poria corticola* and *Poria tenuis*, of two highly unsaturated antibiotics of

* Part IV, Bu'Lock, *J.*, 1955, 575.

peculiar instability. To these the names nemotin and nemotinic acid were given. Both compounds showed characteristic ultraviolet absorption, with sharp maxima at a spacing of *ca.* 2000 cm.$^{-1}$, an interval previously observed with synthetic poly-ynes (Jones, Whiting, Armitage, Cook, and Entwistle, *Nature*, 1951, **168**, 900; Bohlmann, *Chem. Ber.*, 1951, **84**, 545, 785) and with polyacetylenic derivatives of methyl decanoate from various *Compositae* (Sörensen *et al.*, *Acta Chem. Scand.*, 1950, **4**, 416 and later papers). Both antibiotics were strongly dextrorotatory and their ultraviolet spectra showed drastic changes on alkali-treatment indicating rearrangements of the chromophoric groups. These observations of Anchel *et al.* suggested that nemotin and nemotinic acid might contain conjugated double and triple bonds and could conceivably owe their optical activity to asymmetrically substituted allenic groups. In view of the interest in these laboratories in synthetic poly-ynes, a study of these and related antibiotics was undertaken with a view to establishing their structures and structural relations. The subsequently published work of Celmer and Solomons (*J. Amer. Chem. Soc.*, 1952, **74**, 1870 and later papers) on mycomycin (trideca-3 : 5 : 7 : 8-tetraene-10 : 12-diynoic acid) and its isomerisation product (trideca-3 : 5-diene-7 : 9 : 11-triynoic acid) gave some support to the above views and provided a possible analogy for the alkali-instability of nemotinic acid.

Cultures of the antibiotic-producing fungus " B.841 " were kindly supplied by Dr. Anchel, and the fungus was grown in conditions essentially similar to those previously employed. Details of the culture-methods and observations of the effects of varying growth-conditions on polyacetylene production are reported elsewhere (Bu'Lock and Leadbeater, *Biochem. J.*, in the press). The mixture of compounds obtained by ethyl acetate extraction of the culture medium was resolved by Anchel *et al.* (*loc. cit.*), using counter-current distribution between benzene and water, into two fractions, neutral (" nemotin ") and acidic (" nemotinic acid "). When this separation was repeated, with a larger number of transfers studied quantitatively by spectrophotometry, the composite nature of both of these fractions was revealed. The acidic fraction was resolved directly into two components, and redistribution of the neutral material in an aqueous ethanol–*cyclo*hexane system showed that this also consisted of two substances. For the major acidic and neutral components the names nemotinic acid and nemotin are retained, and for the second components of each fraction the names odyssic acid and odyssin are proposed. Odyssic acid and odyssin bear the same relation to each other as do nemotinic acid and nemotin, and will be considered in a separate paper. The relative proportions of these four compounds in the extracts studied are given in Table 1.

TABLE 1. *Yields of polyacetylenes from the culture medium of the fungus* B.841.

Substance	Concn. in medium (mg./l.)	% of total
Nemotinic acid	110	67·5
Nemotin	14	8·5
Odyssic acid	34	21
Odyssin	5	3

All four compounds are unstable in the condensed phase and rapidly undergo polymerisation, particularly on exposure to light. This instability is most marked in nemotin and nemotinic acid; evaporation of solutions of these, even under reduced pressure (nitrogen) and in the dark, gives gums which cannot be completely redissolved. Because of the intractable nature of the compounds, special criteria of homogeneity were required for the present work. One such is provided by quantitative counter-current distribution in suitably chosen solvent systems. Both nemotinic and odyssic acids are obtained substantially pure from the initial benzene–water distribution, as shown by the shape of the distribution curve (Fig. 1), provided that the small intermediate fractions are rejected. The same criterion indicates homogeneity in the nemotin and odyssin obtained by redistribution of the neutral fraction (Fig. 2) and in the methyl ester obtained from nemotinic acid (Fig. 3). By weighing the residues remaining after evaporation of solutions of measured ultraviolet absorption, reproducible and consistent extinction coefficients were obtained for all compounds, and these are probably accurate to within $\pm 3\%$. Reproducible values for molecular rotations were obtained similarly, and the good values obtained for the equivalent

weight of nemotinic acid by this means provided a check upon the method. Careful low-temperature crystallisation of nemotinic acid and its methyl ester at −60° in the dark gave solids, but since these reverted to oils below room temperature and polymerised on exposure to light, elementary analysis of the compounds in an undecomposed state was clearly impracticable. However, no change in weight was detected when a partly decomposed sample of nemotinic acid was completely polymerised by heating it in air at 100°, and elementary analyses of partly or wholly decomposed samples are accordingly given in the Experimental section. They are consistent with the presence of water as the sole major contaminant; complete drying of the polymeric resins is, as might be expected, difficult.

In a recent paper, Anchel and Cohen (*J. Biol. Chem.*, 1954, **208**, 319) recorded the hydrogenation of the neutral component (crude nemotin) and also of its alkali conversion product (nemotin-A) to *n*-undecanoic acid, identified as the *p*-toluidide. We have confirmed this observation, using pure nemotin free from odyssin. In addition to establishing the chain length of nemotin it suggested that nemotin contained a potential carboxyl group in a readily hydrogenolysed form. Anchel and Cohen do not record their yield of undecanoic acid, but we found that hydrogenolysis was incomplete and that the undecanoic acid was accompanied by considerable quantities of a lactone (see below).

Measurement of the infrared absorption spectrum of nemotin revealed the presence of acetylene, allene, acetylenic hydrogen, carbonyl, and methylene groups. The allene band at 1960 cm.$^{-1}$ is sharp and very characteristic (Sheppard and Simpson, *Quart. Rev.*, 1952, **6**, 1), whilst the presence of acetylenic hydrogen was confirmed by the formation of a white

TABLE 2. *Ultraviolet absorption spectra.*

Substance	Absorption max. (Å) and log ε (in parentheses)				
Nemotinic acid	2785 (4·09)	2635 (4·19)	2495 (4·02)	2375 (3·75)	2090 (4·65)
Methyl nemotinate	2785 (4·09)	2635 (4·17)	2495 (3·99)	2375 (3·72)	2090 (4·64)
Nemotin	2780 (4·09)	2625 (4·19)	2490 (4·03)	2365 (3·79)	2085 (4·76)
Nemotin from nemotinic acid ...	2780 (4·09)	2625 (4·19)	2490 (4·03)	2365 (3·79)	2085 (4·74)

photosensitive precipitate with silver nitrate in ethanol. The carbonyl stretching band is at 1790 cm.$^{-1}$, a frequency intermediate between that expected for a saturated γ-lactone (*ca.* 1770 cm.$^{-1}$) and for a $\beta\gamma$-unsaturated γ-lactone (*ca.* 1800 cm.$^{-1}$) (Rasmussen and Brattain, *J. Amer. Chem. Soc.*, 1949, **71**, 1077); the latter possibility is excluded by the absence of absorption near 1680 cm.$^{-1}$ where enol-lactones absorb strongly.

The ultraviolet absorption of nemotin (Table 2) is characteristic of the ene-diyne chromophore; the high-intensity short-wavelength absorption (log ε 4·76 at 2085 Å) distinguishes the spectrum from that of a conjugated diyne acid derivative, which would show similar (though less intense) absorption at the longer wavelengths. The low intensity (ε 3200) of the absorption at the minimum (*ca.* 2300 Å) renders unlikely the presence of any independent diene chromophore (cf. mycomycin, which shows independent absorption by two chromophores, each including one double bond of the allene group).

Combination of the infrared and ultraviolet absorption data with the hydrogenation evidence for a straight chain of eleven carbon atoms leads unambiguously to the structure (I) for nemotin, in which the ester grouping is allylic and hence subject to ready hydrogenolysis. The absence of large alkyl groups in (I) is confirmed by the low intensity (relative to the carbonyl or acetylenic hydrogen band) of the methylene CH stretching bands at 2840 and 2925 cm.$^{-1}$, and the absence of the band at 1380 cm.$^{-1}$ usually ascribed to $-CH_3$. The rather high frequency of the carbonyl band is probably due to the fact that the unsaturated chain of (I) contains carbon atoms in three different hybridisation states and thus exerts an effective dipole; the effect on the carbonyl frequency is then comparable with that observed in γ-acetoxy-γ-lactones and in cyanohydrin acetates (Rasmussen and Brattain, *loc. cit.*). Formula (I) contains two asymmetric centres, the carbon atom $C_{(4)}$ and the allene group, and nemotin is therefore one of the four possible stereoisomers. The structure proposed is completely in accordance with the alkali-catalysed conversion of nemotin into nemotin-A, to be discussed in a later paper.

The major polyacetylenic component of the extracts (Table 1), nemotinic acid, shows

very similar ultraviolet absorption to nemotin, with the maxima uniformly displaced some 10 Å towards longer wavelengths (Table 2), and the infrared spectrum shows the presence of the same unsaturated groups. Thus the molecule also contains the unit $HC{\equiv}C{\cdot}C{\equiv}C{\cdot}CH{=}C{=}CH{\cdot}$ with the allene system not involved in further conjugation. The

$HC{\equiv}C{\cdot}C{\equiv}C{\cdot}CH{=}C{=}CH{\cdot}\overline{CH{\cdot}CH_2{\cdot}CH_2{\cdot}CO{\cdot}O}$ (I)

$HC{\equiv}C{\cdot}C{\equiv}C{\cdot}CH{=}C{=}CH{\cdot}CH(OH){\cdot}CH_2{\cdot}CH_2{\cdot}CO_2H$ (II)

acidity is due to a carboxyl group, whose C=O stretching frequency (1710 cm.$^{-1}$) and pK_a (4·80 in water) show that is is not conjugated. The methylene C–H stretching bands at 2860 and 2920 cm.$^{-1}$ have about the same intensity, relative to the ≡C–H band, as in nemotin; this, together with the equivalent weight (188), suggested a molecule of about the same size as nemotin, with $HC{\equiv}C{\cdot}C{\equiv}C{\cdot}CH{=}C{=}CH{\cdot}$ and $\cdot CH_2{\cdot}CO_2H$ as terminal groups.

The infrared spectrum of nemotinic acid shows several bands not present in that of nemotin, in particular, bands at 3500—3600 cm.$^{-1}$ superimposed on the very broad carboxyl O–H stretching bands. These suggest the presence of a hydroxyl group, and appear clearly in the infrared spectrum of methyl nemotinate (prepared from the acid and diazomethane). Acetylenic hydrogen was detected in the ester by the silver nitrate test. The attempted esterification of nemotinic acid by methanol–sulphuric acid gave a product shown by its infrared spectrum to be a mixture of methyl nemotinate and a γ-lactone. This mixture could be separated by counter-current distribution between aqueous ethanol and *cyclo*hexane; alternatively ester-free lactone could be obtained by the action of sulphuric acid in dry dioxan. The γ-lactone thus prepared is identical with natural nemotin in its ultraviolet and infrared absorption spectra, optical rotation, distribution characteristics, and reaction with alkali. The smooth conversion of nemotinic acid into nemotin requires the former to be one of the four possible stereoisomers of structure (II) which accords fully with the spectroscopic and other evidence discussed above, and also with its reaction with alkali, which will be discussed in a later paper.

Chemical evidence for the structure (II) would substantiate also the structure (I) for nemotin, and it was found possible to prove the chain length and the position of the hydroxyl group by hydrogenation. Direct hydrogenation of nemotinic acid gave a partly lactonised hydroxy-acid, whilst methyl nemotinate similarly gave the methyl ester of a hydroxy-acid. Distillation of either product under reduced pressure gave the same γ-lactone (infrared absorption band at 1775 cm.$^{-1}$), an oil of very characteristic odour. This odour is the same as that of (±)-undecano-γ-lactone, readily prepared by treatment of undecylenic acid with concentrated sulphuric acid at 100°, and the two compounds show identical infrared absorption spectra in carbon disulphide solution. However, the lactone prepared from the antibiotics is optically active ($[\alpha]_D$ +31°) and proof of its formulation as γ-undecanolactone required conversion into an optically inactive material. The hydroxy-amide prepared from the (+)-lactone is crystallographically distinct from the (±)-derivative, but oxidation of the ammonolysis products gave identical samples of 4-oxoundecanamide.

Experimental

So far as possible, unsaturated compounds were handled under nitrogen and in darkness or diffused light. Solutions were concentrated under reduced pressure at 40° or less, and for storage were kept as dilute as practicable; at concentrations greater than about 0·3% decomposition was appreciable in 24 hr. Ultraviolet absorption spectra (Unicam SP-500 Spectrophotometer) and optical rotations were measured in ethanol; for the measurements of infrared spectra, solutions were evaporated in darkness at −50° and the soluble part of the residues taken up in carbon tetrachloride or carbon disulphide. The concentration of polyacetylenes in crude solutions was calculated from the observed difference between optical densities at the longest-wavelength maximum and minimum (*ca.* 2780 and 2710 Å respectively). M. p.s were determined on the Kofler block, and mixed m. p.s confirmed by fusion analysis.

Isolation of Polyacetylenes.—The growth conditions employed are described elsewhere (Bu'Lock and Leadbeater, *loc. cit.*). In a typical experiment, 7 l. of culture medium (containing

ca. 1200 mg. of mixed polyacetylenes) was extracted once with one-fifth and twice with one-tenth its volume of ethyl acetate, and the combined extracts, after spectroscopic assay, were evaporated to *ca.* 400 c.c.; water (400 c.c.) was then added and the evaporation continued until about 100 c.c. of ethyl acetate remained. Ethanol (100 c.c.) was then added to facilitate transfer of polyacetylenes to the aqueous phase, and all organic solvents were finally removed by continued evaporation. The aqueous solution thus obtained contained practically all the original polyacetylenes of the extracts; after storage overnight at 0° it was filtered and placed in the first ten tubes of a 60-plate Craig-type counter-current distribution apparatus (volumes of upper and lower phases 40 c.c.) and fractionated with benzene. Generally about 100 transfers were employed; the neutral polyacetylenes appeared in the first benzene fractions (see below) and the distribution was stopped when odyssic acid began to appear in the benzene fractions being taken off. The odyssic acid was then found near the end of the distribution and the nemotinic acid near the middle (Fig. 1). After discarding intermediate fractions, the total contents of appropriate tubes were evaporated until all the benzene was removed, and the aqueous solutions acidified (pH 4) and extracted rapidly with two portions (one-fifth volume) of peroxide-free ether. The acids were stored in ether at −5° until required (in ethanol some

FIG. 1.

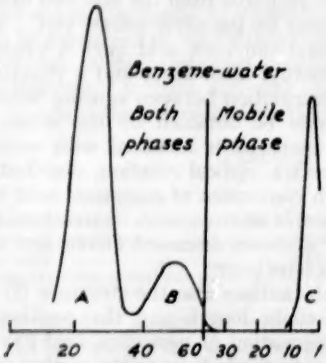


FIG. 2.

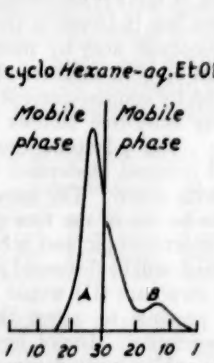
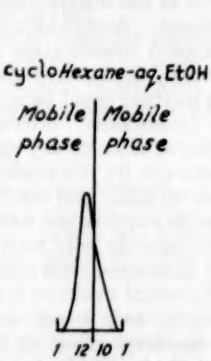


FIG. 3.



Counter-current distribution experiments. (1) *Separation of nemotinic acid (A) and odyssic acid (B) from the neutral fraction (C).* (2) *Resolution of the neutral fraction into nemotin (A) and odyssin (B).* (3) *Purification of methyl nemotinate. For each Figure the curve to the left of the vertical line refers to concentrations (arbitrary units) in successive tubes of the apparatus; that to the right refers to concentrations in fractions taken successively from the last tube of the apparatus.*

esterification took place). The first benzene fractions to be removed from the distribution were combined and the neutral polyacetylenes redistributed between *cyclo*hexane and water containing 30% of ethanol. After 30 transfers, a good separation of nemotin and odyssin was achieved (the nemotin being more soluble in the aqueous layer) though some material was lost in the intermediate (mixed) fractions (Fig. 2). From 1200 mg. of total polyacetylenes there were obtained the following yields of purified polyacetylenes: nemotinic acid 660 mg., odyssic acid 180 mg., nemotin 105 mg., odyssin 15 mg., total 960 mg.

Physical Constants.—Aliquot samples (10 c.c. containing *ca.* 8 mg.) of standard solutions of the purified compounds were evaporated to dryness in tared flasks, and the solid residues were weighed. The average of three such weighings was taken, variation being less than ±5%. The samples were usually partly decomposed; there was no detectable change in weight when decomposition was completed by heating a sample at 100°. For nemotinic acid, analyses were performed on the resin (Found: C, 68·3; H, 5·7. Calc. for $C_{11}H_{10}O_3$: C, 69·5; H, 5·3. Calc. for $C_{11}H_{10}O_3,0{\cdot}2H_2O$: C, 68·2; H, 5·4%), also for nemotin (Found: C, 72·6; H, 5·2. Calc. for $C_{11}H_8O_2$: C, 76·7; H, 4·7. Calc. for $C_{11}H_8O_2,0{\cdot}5H_2O$: C, 72·9; H, 5·0%). The following physical constants were then determined using the standard solutions: for nemotinic acid, $[\alpha]_D^{17}$ +320° (*c*, 0·2); equiv., 186, 188 (Calc. for $C_{11}H_{10}O_3$: 190); pK_a (in water) 4·80; ultraviolet absorption, Table 2; for nemotin, $[\alpha]_D^{17}$ +380° (*c*, 0·3); partition coefficient between *cyclo*hexane and water containing 30% of ethanol by volume, 0·88; ultraviolet absorption, Table 2.

Esterification of Nemotinic Acid.—(*a*) ***With methanol and sulphuric acid.*** A solution of nemotinic acid (200 mg.) and sulphuric acid (0·9 c.c.) in methanol (30 c.c.) was kept in the dark

at 20° for 3 days. The solution was then poured into water and extracted with ether (4 × 50 c.c.), and the combined extracts were washed with sodium hydrogen carbonate solution and water and then dried. The product showed strong infrared absorption at 1790 (lactone) and 1735 cm.$^{-1}$ (ester), and the mixture was resolved by counter-current distribution between *cyclo*hexane and aqueous ethanol.

(b) *With diazomethane.* Nemotinic acid (190 mg.) in ether solution was treated with a slight excess of distilled diazomethane in ether. After 15 min., excess of reagent was decomposed with acetic acid, and the solution was washed with sodium hydrogen carbonate and water and then dried. The infrared absorption of the product showed that no lactonisation had occurred, and the homogeneity of the product was demonstrated by counter-current distribution (Fig. 3). Physical constants for methyl nemotinate were determined as for nemotin : $[\alpha]_D^{17}$ +300° (*c*, 0·35); partition coefficient between *cyclo*hexane and water containing 10% by volume of ethanol, 1·02; ultraviolet absorption, Table 2. Material obtained by evaporation of solutions of purified ester was analysed (Found : C, 68·8; H, 6·0. Calc. for $C_{12}H_{12}O_2$: C, 70·6; H, 5·9. Calc. for $C_{12}H_{12}O_2$,0·3H_2O : C, 68·8; H, 6·0%).

Conversion of Nemotinic Acid into Nemotin.—Nemotinic acid (600 mg.) was transferred from ether into pure dry dioxan (480 c.c.) by evaporating off the ether, and concentrated sulphuric acid (15 c.c.) was added. After 4 days in the dark at room temperature, water (200 c.c.) was added and the solution brought to pH 4 with sodium hydrogen carbonate solution. The precipitated sodium sulphate was filtered off and washed, and the combined filtrate and washings were evaporated to 200 c.c. Water (2 l.) was added and the solution was extracted twice with 400 c.c. portions of ether. The ether extracts contained 470 mg. of neutral polyacetylenes. This material, purified as described for nemotin, gave 350 mg. of pure lactone with $[\alpha]_D^{17}$ +350° (*c*, 0·3) and infrared and ultraviolet absorption spectra identical with those of nemotin. The hydrogenation and alkali-isomerisation behaviour of nemotin were all confirmed with lactonised nemotinic acid.

Hydrogenation of Nemotinic Acid.—Hydrogenation of a solution of the acid (55 mg.) in acetic acid (25 c.c.) over platinum (from 50 mg. of oxide) proceeded with the uptake of *ca.* 5·0 mols. of hydrogen. The solution was filtered and evaporated to give an oil which after distillation under reduced pressure had infrared absorption identical with that of synthetic (±)-γ-undecanolactone and showed $[\alpha]_D^{17}$ +29° (*c*, 1·7), n_D^{20} 1·4540. The lactone (45 mg.) was dissolved in ethanol and the solution was kept saturated with ammonia for 4 days. Evaporation of the solution gave a crude hydroxy-amide which was oxidised directly in acetone solution with excess of chromic acid. Water was added to the reaction mixture and this was extracted continuously with ether. Evaporation of the ether and recrystallisation from benzene–light petroleum gave 4-oxoundecanamide (18 mg.), m. p. 130—131°, undepressed on admixture with synthetic material (see below).

Hydrogenation of Methyl Nemotinate.—Hydrogenation of the ester (105 mg.) in ethanol over platinum proceeded with the uptake of 5·4 mols. of hydrogen to give, after filtration and evaporation, an oil (106 mg.) with the infrared absorption of a hydroxy-ester. On distillation this gave the above (+)-γ-undecanolactone. Ammonolysis of the ester, as described for the lactone, and oxidation of the crude hydroxy-amide (95 mg.) gave 4-oxoundecanamide (35 mg. after recrystallisation) as above.

Hydrogenation of Nemotin with Partial Hydrogenolysis.—Hydrogenation of nemotin (100 mg.) in acetic acid (50 c.c.) containing a trace of perchloric acid over a platinum catalyst proceeded with the uptake of 6·4 mols. of hydrogen; evaporation of the solution gave an oil with infrared absorption bands at 1705 (strong) and 1780 cm.$^{-1}$ (medium), ascribed to acid and lactone respectively. Excess of phosphorus pentachloride was added to the mixture and the products were taken up in dry ether. To the solution was added *p*-toluidine (0·2 g.) in ether, after which the solution was washed successively with dilute hydrochloric acid, sodium carbonate solution, and water. Evaporation of the dried ether solution gave a solid (86 mg.), which when crystallised from light petroleum gave the *p*-toluidide of undecanoic acid, m. p. 78°, undepressed on admixture with authentic material.

(±)-4-*Hydroxyundecanamide and* 4-*Oxoundecanamide.*—γ-Undecanolactone, b. p. 164—166°/13 mm., n_D^{20} 1·4514, prepared by the method of Grün and Wirth (*Ber.*, 1922, **55**, 2217), was treated with an excess of a saturated solution of ammonia in methanol to give (±)-4-*hydroxyundecanamide*, which, crystallised from ethyl acetate–light petroleum, was found to be dimorphous with m. p. 80° and 98—99° (Found : C, 65·65; H, 11·3; N, 7·3. $C_{11}H_{23}O_2N$ requires C, 65·6; H, 11·5; N, 7·0%). Oxidation of this hydroxy-amide in acetone with excess of chromic acid and continuous extraction of the product from the diluted reaction mixture

with ether gave, after crystallisation from ethyl acetate–light petroleum, *4-oxoundecanamide*, m. p. 130—131° (Found: C, 66·45; H, 10·25; N, 7·05. $C_{11}H_{21}O_2N$ requires C, 66·3; H, 10·6; N, 7·05%).

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*Separations of Carbohydrates on Charcoal Columns in the Presence of Borate.**

By S. A. BARKER, E. J. BOURNE, and O. THEANDER.

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Borate complexes of sugars are eluted more readily from charcoal columns than are the sugars themselves. Use is made of this fact in separations of isomeric disaccharides and trisaccharides, and in the fractionation of a homologous series of oligosaccharides. The effect of pH on the efficiency of the separations has been examined, and other applications of the new technique are suggested.

WHISTLER and DURSO's method (*J. Amer. Chem. Soc.*, 1950, **72**, 677) for the fractionation of mixtures of sugars on charcoal columns is now being applied extensively to oligosaccharides (cf. Bailey, Whelan, and Peat, *J.*, 1950, 3692); elution with water containing increasing concentrations of ethanol enables good separations to be effected between mono-, di-, and tri-saccharides, etc., but separations of isomeric saccharides are usually much more difficult to achieve by this method. On the other hand, paper electrophoresis, in the presence of borate buffer (pH 10) (Foster, *J.*, 1953, 982), will separate, on a small scale, mixtures of isomeric saccharides having appropriate structural differences; thus, a glucosaccharide in which the reducing unit is linked through position 2 or position 4 migrates much more slowly than an isomeric glucosaccharide with the reducing unit linked through position 3 or position 6. The purpose of this communication is to report the development of a method for the large-scale separation of isomers, based on the incorporation of borate in the solvent in the usual charcoal-column method and, as a consequence, the extension of the useful range of charcoal columns to cover higher saccharides (of certain structural types) than has been possible hitherto.

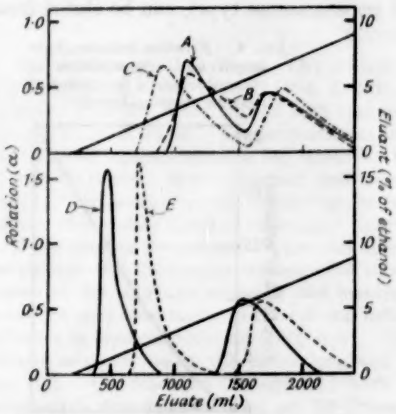
The hypothesis from which the new method was developed was that a carbohydrate–borate complex, which has ionic groups present and at the same time carries a smaller proportion of non-polar regions than the carbohydrate itself, might be expected to assume some of the characteristics of inorganic salts and to move more readily down the column than the parent carbohydrate. The affinity of the carbohydrate for borate was expected to be reflected in the relative times which it spent in the free and the combined state, and hence in the conditions required to remove it from the column, so that a separation between isomeric carbohydrates with different affinities for borate was expected. In addition, it was envisaged that two carbohydrates having similar affinities per molecule for borate, but different molecular weights, might still be separated by virtue of their different affinities for charcoal, the advantage conferred by the borate in this case being that both components would pass more readily through the column than the free sugars. The experiments described below amply confirm these ideas.

In the first group of experiments, the fractionation of a melibiose–maltose mixture was studied, with particular reference to the effect of pH on the efficiency of the separation

* Presented at the XIVth International Congress of Pure and Applied Chemistry, Zürich, 1955.

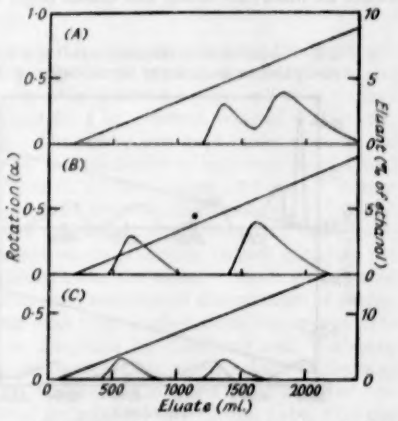
(see Fig. 1). The melibiose, which forms a much stronger borate complex than does maltose, emerged at progressively decreasing concentrations of ethanol (2·7, 2·0, and 0·8%, respectively) as the pH of the borate was increased from 5·3 to 8·5 and then to 10·0; in the absence of borate 3·2% of ethanol was required. The effect of borate on the maltose was much smaller; whereas this disaccharide was eluted with about 5·3% of ethanol in the absence of borate, 4·6% was still required at pH 10·0 in the presence of borate. This pH-dependence of complex formation is in keeping with that found by other methods (cf. Consden and Stanier, *Nature*, **1952**, **169**, 783). In the above cases, as in the others described below, the column was always washed with the appropriate buffer before being used for the fractionation; the reason for this was that the charcoal–" Celite " mixture markedly reduced the pH of the buffer until sufficient buffer had been passed through for an equilibrium state to be reached. The beneficial effect of the prewashing of the column, when borate buffer at pH 10·0 was being used, can be seen in Fig. 1.

FIG. 1. *Separations of melibiose and maltose.*



A, In the absence of added borate.
B, In the presence of boric acid, pH 5·3.
C, In the presence of borate buffer, pH 8·5.
D, In the presence of borate buffer, pH 10·0, column prewashed.
E, In the presence of borate buffer, pH 10·0, column not prewashed.

FIG. 2. *Separation of* iso*maltose from maltose, and of* iso*maltotriose from maltotriose.*



A, Separation of *iso*maltose and maltose in the absence of borate.
B, Separation of *iso*maltose and maltose in the presence of borate buffer, pH 10·0.
C, Separation of *iso*maltotriose and maltotriose in the presence of borate buffer, pH 10·0.

For fractionations of the other mixtures chosen, pH 10·0 was selected. *iso*Maltose, which forms a strong borate complex, was easily separated from maltose; it emerged with 1·2% of ethanol instead of the 4·0% necessary in the absence of borate (Fig. 2). Likewise, the elution of *iso*maltotriose from the column was facilitated by borate, which reduced the alcohol concentration required from 9·3% to 2·8%, and thus enabled a good separation from maltotriose to be effected (Fig. 2).

Each component of the three mixtures separated at pH 10·0 (melibiose–maltose, *iso*maltose–maltose, *iso*maltotriose–maltotriose) was recovered in *ca.* 90% yield as a freeze-dried powder, which was shown to be pure by chromatography and ionophoresis. Slightly higher values were obtained when the yields were calculated from the areas beneath the curves shown in Figs. 1 and 2, comparison being made with the observed rotations of known weights of the sugars, examined under the same conditions.

An alternative use for the new technique is in fractionations of homologous series of oligosaccharides which form strong complexes with borate at one, or both, of the chain ends. In such a case, the normal sequence of the saccharides on charcoal is preserved, but the whole series is eluted more readily than in the absence of borate, thus enabling higher saccharides to be purified than has been possible hitherto. A typical example is to be

found in Fig. 3 where a fractionation of the dextran-type oligosaccharides is shown; nine distinct fractions were obtained by the time that the ethanol concentration reached 23%. An almost linear relation was found between the chain-length of the oligosaccharide (4—10 units) and the concentration of ethanol at which it emerged from the column (Fig. 4). It is probable that even higher saccharides in this series could be obtained, before the solubility limit is reached, by using more ethanol, so that it is not unreasonable to suppose that the new method, with appropriate modifications (*e.g.*, the use of a constant, rather than a decreasing, concentration of borate), might form a basis for the preparation of short-chain dextrans, with a small molecular-size distribution, suitable for sulphation to give heparin substitutes.

The experiments cited are sufficient to indicate that the technique of using charcoal columns with borate buffers as solvents could well find wide application in the carbohydrate field. For example, separations of suitably substituted isomeric derivatives of monosaccharides, polyols, and cyclitols should be readily accomplished. Preliminary experiments already indicate that much larger molecules, which are able to form complexes with borate at intervals along the chain (*e.g.*, those of yeast-mannan type), can be eluted from

FIG. 3. *Separation of the components of a dextran hydrolysate in presence of borate buffer*, pH 10.

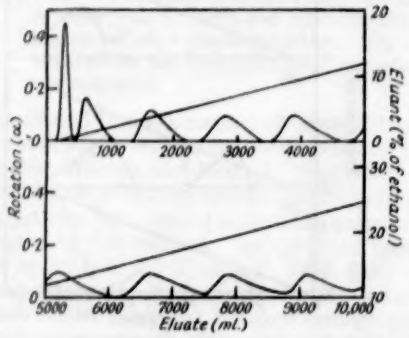
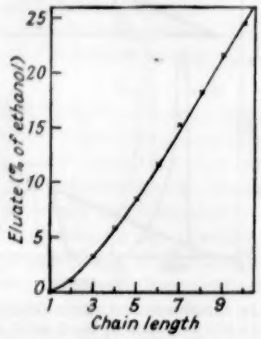


FIG. 4. *Relation between chain length and concentration of ethanol required for elution of dextran oligosaccharides.*



the column in the presence of borate, so that separation of such a polymer from another which does not form a complex is a distinct possibility.

In any individual case, it is necessary to bear in mind the alkali-lability of the components when choosing the pH value for the system; the exclusion of oxygen might be advantageous in preventing degradation in some cases. In our experiments, pH 10·0 was usually employed, since the sugars under investigation were relatively stable to alkali. It is known that even such alkali-labile sugars as nigerose and laminaribiose are stable during paper ionophoresis at this pH (otherwise discrete spots would not be obtained), although they are less stable when not adsorbed on the paper (Barker, Bourne, and O'Mant, unpublished results). For this reason, the sugars were not placed in contact with the buffer before they were adsorbed on the charcoal, and the fractions were acidified immediately they emerged from the column. We believe that, under these conditions, alkaline degradation was negligible, as was indicated by the purities of the products, and by the failure of any product to give a ketose reaction with naphtharesorcinol. In addition, the pH of the system may be an important factor controlling the order of elution of two sugars from the column, since Consden and Stanier (*loc. cit.*) have shown that the electrophoretic mobilities of two sugar–borate complexes may be reversed at two different pH values.

Separations of sugars have already been achieved by elution of their borate complexes from strongly basic anion-exchange resins (Khym and Zill, *J. Amer. Chem. Soc.*, 1952, **74**, 2090; Zill, Khym, and Cheniae, *ibid.*, 1953, **75**, 1339). The fundamental difference

between the two methods is that complex formation decreases the rate of movement of a sugar down a resin column, but increases it on a charcoal column. One result of this is that the use of borate on a resin enables very good fractionations between unsubstituted monosaccharides to be made, whereas borate cannot effect much improvement on charcoal columns since monosaccharides already move very rapidly and are eluted with water alone. However, with mixtures of higher saccharides, the charcoal–borate technique offers advantages because of the contribution to the fractionation made by the charcoal itself. Moreover, the charcoal method seems to be more flexible, as regards both the range of pH values available, and the possibility of using different solvents at different stages in the elution of a single column; for example, it is possible to use a solvent free from borate early in the process to separate the smaller components, and then to introduce borate in the later stages, or in other cases, the borate may be applied initially to remove those saccharides which form complexes, fractionation of the residual sugars being achieved subsequently with a borate-free solvent. To a large extent the two methods are complementary and together they are applicable to a wide variety of problems.

Experimental

Preparation of the Column.—The procedure was similar to that described by Lindberg and Wickberg (*Acta Chem. Scand.*, 1954, **8**, 569). Equal parts of activated charcoal (B.D.H.) and "Celite" (No. 545) were treated with concentrated hydrochloric acid for 1 hr. and then washed thoroughly with water. The mixture was left in ethanol for 1 hr., filtered, washed with water, and dialysed against running tap water for two days. The slurry was kept under vacuum for 30 min. to remove most of the air, and then poured on to thin layers of cellulose powder and "Celite," supported by a porcelain disc, to form a column (*l*, 40 cm.; diam., 2·5 cm.). A new column of the same batch of charcoal–"Celite" was prepared for each fractionation.

Fractionation Procedure.—When the eluting solvent contained borate buffer or boric acid, the column was thoroughly washed with this first (except where otherwise stated) until the pH values of the solutions entering and leaving the column were the same. Small amounts of water (30 ml.) were run into the column before and after the addition of the mixture of carbohydrates in aqueous solution (10% w/v). The column was then washed with the appropriate solvent mixture, using the linear gradient technique described by Lindberg and Wickberg (*loc. cit.*). The fractions (15—20 ml.) were collected in tubes which, when borate buffer was being used, already contained *ca.* 10 drops of 5N-hydrochloric acid; the pH values of the fractions were then 3—5. The separation was followed polarimetrically (2 dm. tube) and the purity of the fractions checked by paper chromatography, with the organic phase of a mixture of butan-1-ol (40%), ethanol (10%), water (49%), and ammonia (1%) as the solvent, and by paper ionophoresis in borate buffer of pH 10·0 (Foster, *loc. cit.*).

Isolation of the Component Sugars.—In the presence of borate, the solution was passed down a column of Amberlite IR-120 (H^+ form), neutralised with silver carbonate, filtered, and evaporated *in vacuo*. Methanol (50 ml.) was distilled twice from the residue, and the product was treated again with a small amount of Amberlite IR-120 and methanol, as before (cf. Zill, Khym, and Cheniae, *loc. cit.*). The purified sugar was extracted with hot methanol, filtered, concentrated, and freeze-dried from aqueous solution. All fractions were dried further for 4 hr. at 60° *in vacuo* over phosphoric anhydride.

Separation of Melibiose and Maltose.—Five mixtures, each containing melibiose dihydrate (1 g.) and maltose hydrate (1 g.), were separated on charcoal–"Celite" columns, which were washed severally by gradient elution with 0—8% aqueous ethanol (2 l.) and then with 8—12% aqueous ethanol (1 l.), each solvent containing the following aqueous solutions in place of the water used in the control experiment (*A*): (*B*) boric acid (7·45 g./l.), pH obtained 5·3; (*C*) boric acid (7·45 g./l.) and sodium hydroxide (1·13 g./l.), pH obtained 8·5; (*D*) boric acid (7·45 g./l.) and sodium hydroxide (4·00 g./l.), pH obtained 10·0; and (*E*) as (*D*), but column previously washed with water only. The separations achieved are shown in Fig. 1. In each case, chromatographic and ionophoretic analyses showed that the first peak was due to melibiose and the second to maltose, and that all the fractions were pure, except where the peaks overlapped. The recoveries of the hydrates of melibiose $\{[\alpha]_D^{19}$ +128·2° (*c*, 2·0 in $H_2O)\}$ and maltose $\{[\alpha]_D^{19}$ +128·1° (*c*, 2·0 in $H_2O)\}$ were 89·9 and 89·5%, respectively, from the column washed as in (*D*).

Separation of iso*Maltose and Maltose.*—Two mixtures, each containing *iso*maltose (0·25 g.)

and maltose hydrate (0·60 g.), were fractionated by gradient elution on charcoal–"Celite" columns. In one case 0—8% aqueous ethanol (2 l.), and then 8—12% (1 l.), was used as the solvent; in the other case, the water was replaced by borate buffer, pH 10·0 (see above). The separations achieved are shown in Fig. 2. Chromatographically pure *iso*maltose {yield, 91·1%; $[\alpha]_D^{19}$ +121·0° (*c*, 2·0 in H_2O)} was recovered from the fractions constituting the first peak, while pure maltose hydrate {yield, 87·1%; $[\alpha]_D^{19}$ +130·5° (*c*, 2·0 in H_2O)} was obtained from those constituting the second, when the eluting solvent contained borate buffer.

Separation of iso*Maltotriose and Maltotriose.*—A mixture of *iso*maltotriose (100 mg.) and maltotriose (100 mg.) was separated on a smaller charcoal column (*l*, 20 cm.; diam., 1·8 cm.) by gradient elution with 0—15% aqueous ethanol (2 l.) containing borate buffer, pH 10·0 (see above). The first of the trisaccharides to be eluted was *iso*maltotriose {yield, 92·4%; $[\alpha]_D^{19}$ +141·2° (*c*, 2·0 in H_2O)}; it was chromatographically pure, as also was the maltotriose {yield, 89·0%; $[\alpha]_D^{19}$ +148·2° (*c*, 2·0 in H_2O)}. The separation achieved is shown in Fig. 2.

Separation of the Homologous Series of Dextran Oligosaccharides.—An essentially unbranched dextran was partially hydrolysed with N-sulphuric acid at *ca.* 95° for 1·5 hr. After neutralisation with barium carbonate, filtration, and freeze-drying, the product was dried at 60°/12 mm. over phosphoric anhydride; it had $[\alpha]_D^{20}$ +144° (*c*, 2·0 in H_2O). A sample (3·15 g.) was separated on a charcoal–"Celite" column (*l*, 40 cm.; diam., 2·5 cm.) by gradient elution with 0—25% aqueous ethanol (10 l.) containing borate, pH 10·0 (see above). The separation is shown in Fig. 3. Portions (100 ml.) of the eluates containing the first four components, taken where the rotation exhibited was a maximum, were worked up and checked by electrophoresis and paper chromatography. Except for the first, which contained a very small amount of fructose, arising from the polysaccharide, they were shown to be pure; they behaved identically to glucose, *iso*maltose, *iso*maltotriose, and *iso*maltotetraose, severally.

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The Conversion of But-2-yne-1 : 4-diol into 2-Deoxyribose.

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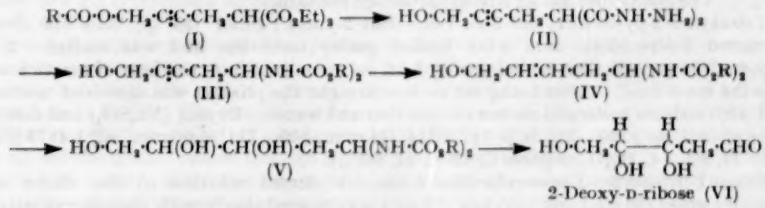
The preparation of monohydric derivatives of but-2-yne-1 : 4-diol is discussed. The condensation of 1-benzoyloxy-4-bromobut-2-yne with ethyl sodiomalonate followed by elaboration of the resulting ethyl 5-benzoyloxypent-3-yne-1 : 1-dicarboxylate (I; R = Ph) gives a small yield of 2-deoxy-DL-ribose isolated as its anilide.

THE occurence of 2-deoxy-D-ribose (VI; written for brevity in the *aldehydo*-form) as a component of one of the nucleic acids has led to a need for a convenient method of preparation of this sugar (for a review see Overend and Stacey, *Adv. Carbohydrate Chem.*, 1953, **8**, 45). When this investigation began all the methods available were unsatisfactory and a total synthesis from non-carbohydrate precursors was therefore studied. Although preparative improvement was not attained the methods used possess intrinsic chemical interest.

The first necessity was a convenient method to transform but-2-yne-1 : 4-diol into a 4-halogenobut-2-yn-1-ol or a derivative thereof. This is achieved most directly by treating the diol with one mol. of thionyl chloride in pyridine whereby 4-chlorobut-2-yn-1-ol is produced (Fraser and Raphael, *J.*, 1952, 226; Colonge and Poilane, *Bull. Soc. chim. France*, 1955, 499, 502; Bailey and Fujiwara, *J. Amer. Chem. Soc.*, 1955, **77**, 165). This product, however, proved highly offensive; not only was the liquid a potent vesicant but even a trace of the vapour frequently provoked an intense dermatitic allergy. A less noxious derivative of this type was found in 1-benzoyloxy-4-bromobut-2-yne, which was readily prepared by the monobenzoylation of but-2-yne-1 : 4-diol and treatment of the resulting half-ester with phosphorus tribromide. Similarly, treatment of the diol with one mol.

of 2 : 3-dihydropyran and reaction of the product with phosphorus tribromide gave the non-toxic 4-bromo-1-(tetrahydro-2-pyranyloxy)but-2-yne in fair yield. A preparation of 1-acetoxy-4-chlorobut-2-yne by reaction of 1 : 4-dichlorobut-2-yne with one mole of potassium acetate gave poor yields of the required product.



Condensation of 1-benzoyloxy-4-bromobut-2-yne with ethyl sodiomalonate gave the expected ethyl 5-benzoyloxypent-3-yne-1 : 1-dicarboxylate (I; R = Ph) which was converted by hydrazine into the dihydrazide (II), the benzoyl group being removed as benzhydrazide. The product (II) was then subjected to a double Curtius degradation; reaction with nitrous acid, followed by treatment of the resulting diazide with methanol or ethanol, produced the acetylenic diurethane (III; R = Me or Et). Partial catalytic hydrogenation of this product gave the corresponding *cis*-ethylenic diurethane (IV). *cis*-Hydroxylation of this compound, using either dilute potassium permanganate or osmium tetroxide–hydrogen peroxide, yielded the *erythro*-triol (V) (Raphael, *J.*, 1949, S 44). Considerable difficulty was encountered in the hydrolysis of this product. Similarly constituted diamide derivatives of carbohydrates have usually been hydrolysed to the free sugar by hot mineral acid. Unfortunately 2-deoxyribose is very sensitive towards acidic reagents and much experimentation was needed before conditions could be established which enabled hydrolysis to take place with minimal destruction of the sugar. Even so, the yield of 2-deoxy-DL-ribose was very small; treatment of the crude product with aniline gave the crystalline anilide of the sugar identical with an authentic specimen.

In another approach to the *erythro*-triol (V) the acetylenic diurethane (III) was converted into the *trans*-ethylenic diurethane (IV) by reduction with sodium in liquid ammonia. The yield of the latter urethane was low, however, because of the formation of a by-product, *trans*-1 : 1-di(methoxycarbonylamino)pent-3-ene, obviously produced by reductive fission of the allylic hydroxyl group. This fission was, however, completely suppressed by carrying out the reduction on the sodium derivative from the diurethane (III), prepared *in situ* by the initial addition of sodamide. Treatment of the *trans*-ethylenic diurethane (IV) with perbenzoic acid gave the expected epoxide; however, attempts simultaneously to hydrate the epoxide ring and to hydrolyse the diurethane grouping failed.

Experimental

4-Benzoyloxybut-2-yn-1-ol.—The method is a modification of that used by Jones and Sondheimer (*J.*, 1949, 616) for the preparation of quinitol monobenzoate. But-2-yne-1 : 4-diol (95 g.), dissolved in a mixture of dry benzene (250 c.c.) and dry pyridine (110 c.c.), was cooled to 0° and benzoyl chloride (110 c.c.) in dry chloroform (200 c.c.) was added with stirring during 4 hr., the temperature being kept below 5°. Cooling was then stopped and the stirring continued for a further 4 hr. The solution was then washed with N-sulphuric acid (4 × 100 c.c.), followed by water (3 × 100 c.c.), and dried (Na_2SO_4); ethanol (150 c.c.) was then added and the solution kept at −16° overnight. The resulting crystalline dibenzoate (45 g., m. p. 75—76°) of but-2-yne-1 : 4-diol was filtered off. Evaporation of the solvent from the filtrate, followed by distillation, gave the *monobenzoate* (102 g., 61%) as an oil, b. p. 117°/8 × 10^{-4} mm., n_D^{19} 1·5510 (Found: C, 69·45; H, 5·25. $C_{11}H_{10}O_3$ requires C, 69·5; H, 5·3%). The *phenylurethane* crystallised from benzene–light petroleum (b. p. 60—80°) in needles, m. p. 120° (Found: N, 4·6. $C_{18}H_{15}O_4N$ requires N, 4·5%).

1-Benzoyloxy-4-bromobut-2-yne.—To a stirred solution of the above monobenzoate (70 g.) in benzene (1 l.) was added dropwise phosphorus tribromide (25 c.c.); stirring was continued at room temperature for 24 hr. Iced water was then added and the aqueous layer extracted with

ether. The combined organic layers were washed with sodium hydrogen carbonate solution and water and dried (Na_2SO_4), and the solvent evaporated off. Distillation gave **1-*benzoyloxy*-4-*bromobut*-2-*yne*** (75 g., 81%) as a colourless liquid, becoming yellow at room temperature, b. p. 104—106°/8 × 10^{-6} mm., n_D^{18} 1·5744 (Found: C, 52·35; H, 3·8. $C_{11}H_9O_2Br$ requires C, 52·2; H, 3·6%). The compound has an irritant action on the skin.

4-(*Tetrahydro*-2-*pyranyloxy*)*but*-2-*yn*-1-*ol*.—But-2-yne-1:4-diol (35 g.) and six drops of concentrated hydrochloric acid were heated gently until the diol was molten. 2:3-Dihydropyran (34 g.) was then added during 1 hr. to the stirred diol, the heat of reaction serving to keep the mass fluid. After being set aside overnight the product was dissolved in ether and washed with sodium hydrogen carbonate solution and water. Drying (Na_2SO_4) and distillation gave the *alcohol*, m. p. 20—24°, b. p. 142—144°/14 mm., 109—111°/0·05 mm., n_D^{24} 1·4873 (Found: C, 63·5; H, 8·1. $C_9H_{14}O_2$ requires C, 63·5; H, 8·3%).

4-*Bromo*-1-(*tetrahydro*-2-*pyranyloxy*)*but*-2-*yne*.—A stirred solution of the above alcohol (8 g.) in dry ether (50 c.c.) and pyridine (10 c.c.) was treated slowly with phosphorus tribromide (2 c.c.) in ether (15 c.c.), and the solution left at room temperature overnight. It was then washed with dilute sulphuric acid, sodium hydrogen carbonate solution and water; drying, evaporation, and distillation gave the *bromo-ether* (4·1 g., 40%) as an oil which rapidly discolours at room temperature, b. p. 70°/0·05 mm., n_D^{24} 1·5246 (Found: C, 46·2; H, 5·5. $C_9H_{13}OBr$ requires C, 46·4; H, 5·6%).

Use of thionyl chloride and pyridine in the above reaction gave the corresponding *chloro-ether* (30%), b. p. 92—94°/13 mm., n_D^{20} 1·4912 (Found: C, 57·0; H, 7·0. $C_9H_{13}OCl$ requires C, 57·3; H, 7·0%).

1-*Acetoxy*-4-*chlorobut*-2-*yne*.—1:4-Dichlorobut-2-yne (16·5 g.; Johnson, *J.*, 1946, 1009), anhydrous potassium acetate (13·1 g., 1 mol.), and acetic acid (50 c.c.) were refluxed for 21 hr. The precipitated potassium chloride was filtered off and the bulk of the acetic acid removed by distillation. The residue was poured into water (50 c.c.), and the product isolated by ether. Drying, evaporation, and fractionation gave **1-*acetoxy*-4-*chlorobut*-2-*yne*** (4·6 g., 23%), b. p. 98—100°/14 mm., n_D^{20} 1·4720 (Found: C, 49·25; H, 4·9. $C_6H_7O_2Cl$ requires C, 49·2; H, 4·8%).

Ethyl* 5-*Benzoyloxypent*-3-*yne*-1:1-*dicarboxylate (I; R = Ph).—Diethyl malonate (16 g.) was added dropwise to a stirred suspension of atomised sodium (2·3 g.) in toluene (250 c.c.) and the mixture heated for 4 hr. at 50°. 1-Benzoyloxy-4-bromobut-2-yne (25·3 g.) was then added during 30 min. at 50°, and the mixture heated at 100° for 16 hr. The cooled solution was washed with dilute sulphuric acid and water, and dried (Na_2SO_4) and the solvent removed under reduced pressure. Distillation gave the *ester* (22·5 g., 77%), b. p. 142—144°/8 × 10^{-5} mm., n_D^{20} 1·5056 (Found: C, 64·75; H, 5·8. $C_{18}H_{20}O_6$ requires C, 65·05; H, 6·05%).

An analogous reaction with 1-acetoxy-4-chlorobut-2-yne gave the corresponding *acetoxy-ester* (I; R = Me), b. p. 98—99°/10^{-4} mm., n_D^{22} 1·4549 (Found: C, 57·65; N, 6·65. $C_{13}H_{18}O_6$ requires C, 57·75; H, 6·7%).

5:5-*Di*(*hydrazinocarbonyl*)*pent*-2-*yn*-1-*ol* (II).—A mixture of the above benzoyl ester (21·2 g.) and an equal volume of hydrazine hydrate (100%) was heated in an oil-bath at 120° for 8 min. with vigorous shaking. Boiling ethanol (300 c.c.) was then added and the flask cooled to 0°. The precipitated *dihydrazide* was filtered off and crystallised from aqueous ethanol (90%) as needles (8·65 g., 68%), m. p. 145°. The compound is extremely water-soluble (Found: C, 42·2; H, 5·9. $C_7H_{12}O_3N_4$ requires C, 42·0; H, 6·0%).

5:5-*Di*(*methoxycarbonylamino*)*pent*-2-*yn*-1-*ol* (III; R = Me).—The above dihydrazide (10·7 g.) was dissolved in dilute sulphuric acid (concentrated acid, 5·7 c.c.; water, 50 c.c.), and a layer of ether (60 c.c.) added. The mixture was cooled to −8° and excess of sodium nitrite (15 g.) in water (30 c.c.) chilled to −8° was added during 15 min. with vigorous swirling, the temperature being kept below −4°. After 5 min. the green ether layer was decanted off and the semi-solid residue extracted as quickly as possible with ice-cold ether (5 × 50 c.c.). The combined extracts were washed with ice-water (50 c.c.) and dried (Na_2SO_4) at 0° for 30 min. To the filtered solution was added methanol (100 c.c.), and the ether removed by distillation; the resulting solution was refluxed for 4 hr. After removal of solvent the crude product (6·5 g.) was crystallised from ethyl acetate to give the *diurethane* (5·6 g., 84%) as needles, m. p. 116° (Found: C, 47·1; H, 5·9; N, 12·3. $C_9H_{14}O_5N_2$ requires C, 46·95; H, 6·1; N, 12·2%).

By employing ethanol in place of methanol the *diethyl analogue* (III; R = Et) was obtained, although in lower yield (37%). It crystallised from chloroform–carbon tetrachloride (1:4) in prisms, m. p. 138° (Found: C, 51·0; H, 7·05; N, 10·85. $C_{11}H_{18}O_5N_2$ requires C, 51·15; H, 7·0; N, 10·85%).

cis-5:5-*Di*(*ethoxycarbonylamino*)*pent*-2-*en*-1-*ol* (IV; R = Et).—The above ethyl diurethane

(7·37 g.) in ethyl acetate (150 c.c.) was shaken with hydrogen in the presence of 10% palladium–charcoal (400 mg.). The theoretical volume of hydrogen (803 c.c. at 21°/762 mm.) was absorbed in 30 min. The crude product, after removal of catalyst and solvent, was suspended in boiling light petroleum (b. p. 60—80°), and ethyl acetate added until solution was effected. The *cis-diurethane* (5·1 g.) crystallised as needles, m. p. 92° (Found : C, 50·75; H, 7·7. $C_{11}H_{20}O_5N_2$ requires C, 50·75; H, 7·7%).

erythro-5 : 5-*Di*(*ethoxycarbonylamino*)*pentane*-1 : 2 : 3-*triol* (V; R = Et).—(*a*) To a vigorously stirred solution of the above *cis*-diurethane (1·3 g.) in ice-water (30 c.c.), through which carbon dioxide was bubbling, was added aqueous potassium permanganate (2%; 30 c.c.) dropwise during 20 min. at 0—3°. The temperature was allowed to rise to 10° and a few drops of ethanol were added to destroy excess of permanganate. The precipitated manganese dioxide was filtered off and the filtrate passed through a column of cation-exchange resin (Amberlite IRC-50) to remove potassium. After extraction with chloroform the aqueous solution was taken to dryness under reduced pressure at room temperature. The residual glass was dissolved in dry ethanol, and the solution filtered and again taken to dryness under reduced pressure. The product was dried *in vacuo* over phosphoric oxide. The resulting *triol* was a glassy water-soluble solid which did not crystallise (Found : C, 44·3; H, 8·3; N, 9·1. $C_{11}H_{22}O_7N_2$ requires C, 44·9; H, 7·55; N, 9·5%).

(*b*) The *cis*-diurethane (0·5 g.) was dissolved in a 2·5M-solution (0·8 c.c.) of hydrogen peroxide in *tert.*-butyl alcohol and cooled to 0°. Two drops of a 0·5% solution of osmium tetroxide in *tert.*-butyl alcohol were added; an orange colour developed immediately. After 20 hr. at 0° the solvent was removed under reduced pressure to give the above triol.

2-*Deoxy*-DL-*ribose*.—A solution of the above triol (1·1 g.) in 0·1% sulphuric acid (30 c.c.) was kept in a boiling water-bath for 6 min. The solution was then rapidly cooled and passed through a column of anion-exchange resin (Amberlite IR-4B pre-saturated with carbon dioxide). Evaporation of the effluent to dryness under reduced pressure at room temperature gave a thick syrup which did not crystallise. It reduced Fehling's solution and gave an intense, stable blue colour with the Dische reagent (Deriaz, Stacey, Teece, and Wiggins, *J.*, 1949, 1222). Treatment of this product with ethanolic aniline by the usual procedure (Kent, Stacey, and Wiggins, *J.*, 1949, 1232) gave, after evaporation, a thick syrup. This was rendered more fluid by the addition of a few drops of dry ethanol and set aside at 0° for 2 days. Ice-cold ethanol was then added and the suspended solid rapidly centrifuged off. Crystallisation from a small volume of dry ethanol gave *N*-2-deoxy-DL-ribosylaniline (8 mg.), m. p. 154—156° (Kofler block) undepressed on admixture with an authentic sample prepared by mixing equal weights of the enantiomorphs. The *X*-ray powder photographs of the two samples were identical (we cordially thank Professor J. M. Robertson, F.R.S., for arranging these determinations).

trans-5 : 5-*Di*(*methoxycarbonylamino*)*pent*-2-*en*-1-*ol* (IV; R = Me).—To a stirred solution of 5 : 5-di(methylcarbonylamino)pent-2-yn-1-ol (III; R = Me) (5·06 g.) in liquid ammonia (600 c.c.) was added finely ground sodamide (0·85 g.). After 10 min. metallic sodium (2·02 g.) was added in small pieces. Stirring was continued for 8 hr., more sodium (total 1 g.) being added from time to time to keep the solution blue. Ammonium chloride (10 g.) was then introduced and the ammonia allowed to evaporate overnight. Extraction with hot ethyl acetate and crystallisation of the crude product from ethyl acetate–light petroleum (b. p. 60—80°) (1 : 1) gave the trans-*diurethane* (3·03 g., 60%) as prisms, m. p. 101—102° (Found : C, 46·45; H, 6·7. $C_9H_{16}O_5N_2$ requires C, 46·55; H, 6·95%). Microhydrogenation disclosed 1 double bond.

When the sodamide was omitted from the preparation, the yield of the above compound dropped to 24%, the major constituent of the product being trans-1 : 1-*di*(*methoxycarbonylamino*)*pent*-3-*ene*, needles, m. p. 123—124° [from methanol–light petroleum (b. p. 60—80°) (4 : 1)] (Found : C, 50·2; H, 6·8; N, 13·3. $C_9H_{16}O_4N_2$ requires C, 50·0; H, 7·4; N, 13·0%). Microhydrogenation disclosed 0·95 double bond.

Treatment of the above hydroxy-diurethane (0·5 g.) in chloroform (4 c.c.) with chloroformic perbenzoic acid (4·45% w/v; 6·65 c.c.) at 0° gave the *epoxide*, crystallising from ethyl acetate in prisms, m. p. 122° (Found : C, 43·75; H, 6·5; N, 11·4. $C_9H_{16}O_6N_2$ requires C, 43·55; H, 6·5; N, 11·3%). Attempted hydrolyses of this compound gave no recognisable product.

We are grateful to Professor M. Stacey, F.R.S., and to Dr. G. N. Richards for kindly providing samples of 2-deoxy-L- and -D-ribose respectively.

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The Synthesis of Furano(3′ : 2′-3 : 4)quinolines and the Structure of Dictamnic Acid.

By M. F. Grundon, N. J. McCorkindale, and (in part) M. N. Rodger.

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The dihydrofuranoquinolones (VI; R = H and R = OMe) have been prepared from diethyl (2-ethoxyethyl)malonate and aromatic amines, and one of these (VI; R = H) has been converted into 2-methoxyfurano (3′ : 2′-3 : 4)quinoline, an isomer of the alkaloid dictamnine. The structures of the products have been established by degradation and infrared and ultraviolet spectroscopy.

The structure of ethyl dictamnate has been confirmed by its conversion into 3-carboxy-2-chloro-4-methoxyquinoline.

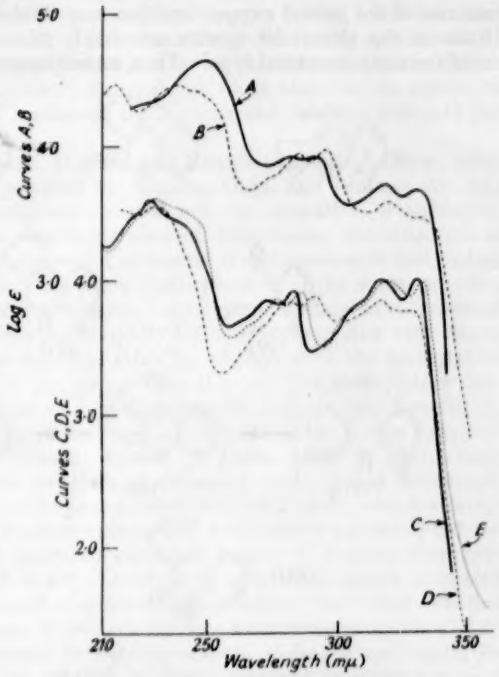
The alkaloid dictamnine has been assigned structure (I; R = R′ = H) (Asahina, Ohta, and Inubuse, *Ber.*, 1930, **63**, 2045). Most of the degradative experiments did not distinguish between structures (I) and (II), but the linear structure was favoured by the isolation of an oxidation product, dictamnic acid (III; R = H). Asahina *et al.* (*loc. cit.*) did not synthesise dictamnic acid, but showed that it was not identical with a synthetic compound thought to be the isomeric acid (IV). The structures of other furanoquinoline alkaloids such as γ-fagarine (I; R = OMe, R′ = H) (Berinzaghi, Muruzabal, Labriola, and Deulofeu, *J. Org. Chem.*, 1945, **10**, 181) and skimmianine (I; R = R′ = OMe) (Asahina and Inubuse, *Ber.*, 1930, **63**, 2052) were derived by analogy with dictamnine. In view of the inconclusive nature of this evidence we investigated the synthesis of furanoquinolines and confirmed the structure of dictamnic acid.

Furanopyridines and furanoquinolines have been prepared previously from α-pyrone derivatives (Asahina and Inubuse, *Ber.*, 1932, **65**, 61; Robinson and Watt, *J.*, 1934, 1536), but the preparation of dihydrofuranopyridines from 3-substituted 2-pyridones (Matejka, Robinson, and Watt, *J.*, 1932, 2019; Stephens, Beutel, and Chamberlin, *J. Amer. Chem. Soc.*, 1942, **64**, 1093) suggested a more direct method. Ethyl (2-ethoxyethyl)malonate condensed with aniline in boiling diphenyl ether to give a dihydrofuranoquinolone by the elimination of 3 mols. of ethanol. Only one of the two possible isomers (V or VI; R = H) was obtained. Similarly, *o*-anisidine, in the same condensation, gave only a single component (V or VI; R = OMe). The isolation of 3-2′-ethoxyethyl-2 : 4-dihydroxy-8-methoxyquinoline after only 2 mols. of ethanol had been evolved suggested that dihydroxyquinolines are intermediates in this type of condensation, at least in the reaction with *o*-anisidine. The dihydrofuranoquinolone (V or VI; R = H) with phosphorus oxychloride gave 2 : 4-dichloro-3-2′-chloroethylquinoline.

The two dihydrofuranoquinolones (V or VI; R = H and R = OMe) gave the corresponding furanoquinolones (VII or VIII; R = H and R = OMe) by dehydrogenation with palladium–charcoal. The melting point (250°) of one of these compounds (VII or VIII; R = H) corresponded with the value of 249° given for nordictamnine (VII; R = H) derived from the alkaloid, but no sample of the natural material was available for comparison.

Witkop, Patrick, and Rosenblum (*J. Amer. Chem. Soc.*, 1951, **73**, 2641) have recommended the use of infrared and ultraviolet spectra to distinguish between 2- and 4-quinolones. Model compounds (for example, Nos. 6—11, Table) suggest that 2-quinolones have strong amide-carbonyl absorption at 1660—1650 cm.$^{-1}$, whereas 4-quinolones absorb at a lower frequency (1630—1620 cm.$^{-1}$). The two synthetic dihydrofuranoquinolones and the derived furanoquinolones show strong absorption bands at the higher frequency (Table), and thus appear to be 2-quinolones of structures (VI and VIII; R = H and R = OMe). The position of the amide band in the infrared spectra of variously substituted 2-quinolones (Table; see also Grundon and Boekelheide, *J. Amer. Chem. Soc.*, 1952, **74**, 2637) remains fairly constant, and should be of general use in recognising this type of system. The peak attributed to amide absorption in 4-quinolones may easily be confused

with quinoline ring vibrations, and, further, strong absorption in this region (1620—1630 cm.$^{-1}$) also occurs in some 2-quinolones (Table). Short and Thompson (*J.*, 1952, 168) discussed this apparent doublet in the spectra of related hydroxypyrimidines. The degree



Ultraviolet light absorption in ethanol of 1 : 2-*dihydro*-8-*methoxy*-2-*oxofurano*(3′ : 2′-3 : 4)*quinoline* (*A*), 1 : 2 : 4′ : 5′-*tetrahydro*-8-*methoxy*-2-*oxofurano*(3′ : 2′-3 : 4)*quinoline* (*B*), 1 : 2-*dihydro*-2-*oxofurano*(3′ : 2′-3 : 4)*quinoline* (*C*), 1 : 2 : 4′ : 5′-*tetrahydro*-2-*oxofurano*(3′ : 2′-3 : 4)*quinoline* (*D*), *and* 1 : 2-*dihydro*-1-*methyl*-2-*oxofurano*(3′ : 2′-3 : 4)*quinoline* (*E*).

of hydrogen bonding in those compounds whose spectra were determined in the solid state introduces a variable factor, which makes interpretation less reliable.

The ultraviolet spectra of a number of quinolones (see, for example, Ewing and Steck, *J. Amer. Chem. Soc.*, 1946, **68**, 2181; Steck, Ewing, and Nachod, *ibid.*, 1949, **71**, 238;

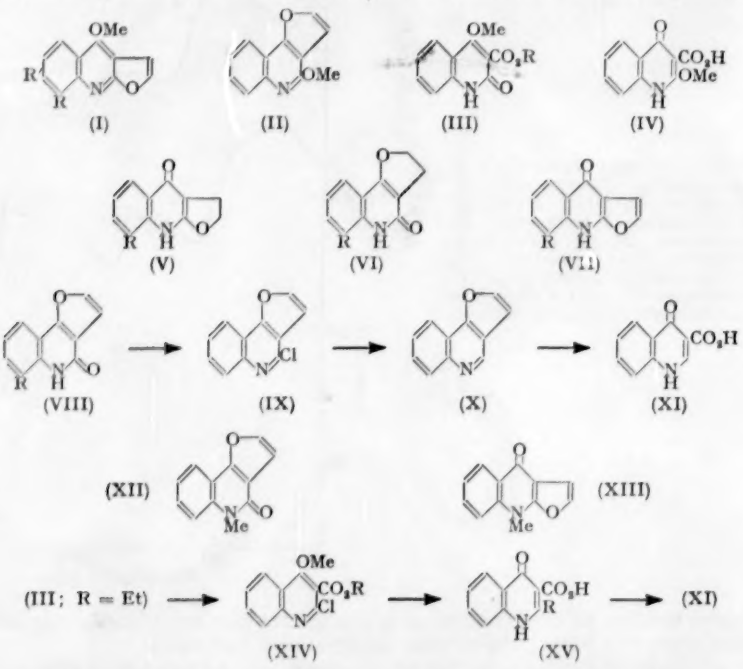
Infrared * *absorption bands in the region* 1800—1480 cm.$^{-1}$ *of* 2- *and* 4-*quinolones in Nujol suspensions* (*except when stated otherwise*).

No.	Substance	CO_2R	2-Quinolone amide I	4-Quinolone amide I	Other 5—6 μ bands
1	(VI; R = H)	—	1655 s	—	1625 m, 1606 m, 1585 m, 1507 m
2	(VI; R = OMe)	—	1654 s	—	1630 s, 1580 m, 1500 m
3	(VIII; R = H)	—	1660 s	—	1635 m, 1610 m, 1570 m
4	(XII)	—	1660 s	—	1590 m, 1510 m
5	(VIII; R = OMe)	—	1655 s	—	1600 m, 1505 m
6	2-Quinolone	—	1650 s	—	1605 m, 1555 m, 1505 w
7	4-Quinolone †	—	—	1628 m	1610 s, 1590 s, 1555 s, 1503 s
8	3 : 4-*cyclo*Penteno-2-quinolone [a]	—	1659 s	—	—
9	2 : 3-*cyclo*Penteno-4-quinolone [a]	—	—	1626 s	—
10	3-Carboxy-4-quinolone (XI) †	1670 s	—	1620 s	1580 m, 1517 m
11	Me ester of (XI) [b] ‡	1690 s	—	1630 s	1610 m, 1590 s, 1514 m
12	3-Ethoxycarbonyl-4-methoxy-2-quinolone	1730 m	1643 m	—	1600 s, 1498 s
13	(XIV; R = H) †	1710 m	—	—	1612 w, 1575 s, 1510 m
14	(XV; R = Cl) †	1690 s	—	1620 s	1555 m, 1520 s

* Spectra were determined with a Perkin–Elmer Model 13 (Double Beam) Spectrometer (NaCl prism). † KCl disc. ‡ In $CHCl_3$.

[a] Witkop *et al.*, *loc. cit.* [b] Grundon and Bockelheide, *loc. cit.*

Witkop *et al., loc. cit.*) indicate that 2-quinolones have strong absorption at 2700—2850 Å which in 4-quinolones is either absent or appears as a shoulder. The ultraviolet spectra of the four synthetic compounds under consideration (see Figure) conform to the 2-quinolone pattern in having bifurcated peaks in the region 2730—2950 Å, although the presence of the second oxygen function may diminish the significance of this comparison. However, the ultraviolet spectra are closely related and show that the four compounds are of the same structural type. Thus, no rearrangement occurred during dehydrogenation.



The quinolones are insoluble in dilute aqueous alkali and fail to react with diazomethane. This lack of acidity is characteristic of 3-substituted 2-quinolones (Lamberton and Price, *Austral. J. Chem.*, 1953, **6**, 66; Arndt, Ergener, and Kutlu, *Chem. Ber.*, 1953, **86**, 951). Further, the very faint ferric chloride reactions given by these compounds are in accord with 2-quinolone structures. Proof of this conclusion was provided by the series of reactions (VIII ⟶ XI). The chlorofuranoquinoline (IX), prepared from the furanoquinolone (VIII; R = H) with phosphorus oxychloride, was unaffected by lithium aluminium hydride in ether or tetrahydrofuran. Reduction with zinc and sulphuric acid gave some furanoquinoline (X), and the small yield was possibly due to extensive hydrolysis to the furanoquinolone (VIII; R = H). The furanoquinoline (X) was prepared in good yield by conversion of the chlorofuranoquinoline into the corresponding hydrazine, which was reduced with aqueous copper sulphate. The isolation of 3-carboxy-4-quinolone (XI) by oxidation of the furanoquinoline with potassium permanganate provided convincing proof of the angular structure of the precursors.

The chlorofuranoquinoline (IX), by reaction with sodium methoxide in methanol, gave the corresponding methoxyfuranoquinoline (II), m. p. 52—53°, clearly not identical with dictamnine (m. p. 133°).

Methylation of the furanoquinolone (VIII; R = H) with methyl sulphate and alkali gave the *N*-methyl ether (XII), m. p. 130°. This compound cannot be identical either with *iso*dictamnine (XIII), m. p. 188°, or with a compound, m. p. 225° which was synthesised

from 3-formyl-2 : 4-dihydroxyquinoline through the α-pyrone derivative and assigned structure (XII) (Asahina and Inubuse, *Ber.*, 1932, **65**, 61). In view of this confusion the purity of our *N*-methyl ether was examined carefully, and chromatography showed it to be homogeneous. The conditions used for its preparation could conceivably have led to the rearrangement of the furanoquinolone system (see, for example, Lahey, Lamberton and Price, *Austral. J. Sci. Res.*, 1950, **3**, *A*, 155). The ultraviolet and infrared spectra of this product (Fig. and Table), which were very similar to that of the furanoquinolone (VIII; R = H), indicated that no such rearrangement occurred. It must, therefore, be concluded that the synthetic product, m. p. 225°, obtained by Asahina and Inubuse (*loc. cit.*) has some other structure.

The recent discovery by Brown, Hobbs, Hughes, and Ritchie (*Austral. J. Chem.*, 1954, **7**, 348) that the quinoline derivative prepared by Asahina, Ohta, and Inubuse (*loc. cit.*) was 2 : 4-dihydroxy-3-methoxycarbonylquinoline and not, as supposed, 3-carboxy-2-methoxy-4-quinolone (IV), emphasises the importance of determining the structure of dictamnic acid. Brown *et al.* (*loc. cit.*) reported a synthesis of dictamnic acid and, before the Australian publication was available, the same synthesis, with slight variations, was carried out in this laboratory (by Mr. M. N. Rodger). An important stage in this method involves the monomethylation of 3-ethoxycarbonyl-2 : 4-dihydroxyquinoline with diazomethane, which is assumed to give the 4-methyl ether by analogy with the methylation of 2 : 4-dihydroxyquinoline (Arndt *et al.*, *loc. cit.*). That this selective methylation does not always occur is shown by the reaction of 2 : 4-dihydroxy-6 : 7-dimethoxy-3-methoxycarbonylquinoline and diazomethane to give the dimethyl ether, and the failure to isolate a monomethyl ether is this reaction (Brown, *Austral. J. Chem.* 1955, **8**, 121). Such ambiguity demands further proof of the structure of dictamnic acid. Ethyl dictamnate (III; R = Et) with phosphorus oxychloride gave a small yield of 2 : 4-dichloro-3-ethoxycarbonylquinoline (also prepared from 3-ethoxycarbonyl-2 : 4-dihydroxyquinoline) but the principal product, obtained as an oil, probably consisted largely of 2-chloro-3-ethoxycarbonyl-4-methoxyquinoline (XIV; R = Et). Analysis of a distilled sample indicated some contamination with 2 : 4-dichloro-3-ethoxycarbonylquinoline, but brief alkaline hydrolysis of the crude material gave 3-carboxy-2-chloro-4-methoxyquinoline (XIV; R = H). The solubility of this compound in aqueous sodium hydrogen carbonate, its negative ferric chloride reaction, and its infrared spectrum (absence of amide-carbonyl absorption; Table) indicated that this compound was indeed a carboxymethoxyquinoline and not the isomeric methyl hydroxy-ester which might conceivably have been obtained by ester exchange. The methoxy-acid, on more prolonged alkaline hydrolysis, gave 3-carboxy-2-chloro-4-quinolone (XV; R = Cl), identical in properties with an oxidation product of chlorodeoxyflindersine, to which this structure was also ascribed (Brown *et al.*, *loc. cit.*). In the present work this assignment was confirmed by the conversion of the chloro-acid (XV; R = Cl) into the hydrazino-derivative (XV; R = NH·NH_2), which was reduced with aqueous copper sulphate to 3-carboxy-4-quinolone (XI). This series of reactions (III; R = Et) ⟶ (XI) establishes the structure of dictamnic acid.

Experimental

Diethyl (2-Ethoxyethyl)malonate (Prelog and Bozicevic, *Ber.*, 1939, **72**, 1103).—In the preparation of the intermediate sulphonate, cooling the mixture of 2-ethoxyethanol and benzene sulphonyl chloride in ice–salt allowed more rapid addition of the aqueous sodium hydroxide. After reaction with diethyl malonate, the sulphonate gave diethyl (2-ethoxyethyl)malonate, fractionally distilled as a colourless oil (70% yield, based on 2-ethoxyethanol; Prelog *et al.*, *loc. cit.*, report 47%), b. p. 84—94°/0·6—0·8 mm., n_D^{16} 1·4284.

1 : 2 : 4′ : 5′-*Tetrahydro-2-oxofurano*(3′ : 2′-3 : 4)*quinoline* (VI; R = H).—A mixture of diethyl (2-ethoxyethyl)malonate (20 g.), aniline (7·3 g.), and diphenyl ether (250 c.c.) was heated under reflux. The evolution of ethanol ceased after 3 mols. (12 c.c.) had been collected (4½ hr.), but heating was continued for a further 1½ hr. The addition of light petroleum (b. p. 60—80°; 1 l.) gave a yellow precipitate (13·2 g.). By crystallisaton from pyridine, the *dihydrofuranoquinolone* was obtained as pale yellow prisms (6·68 g.), m. p. 272—275° (decomp.), raised to 280—281° (decomp.) by recrystallisation from pyridine or methanol (Found: C, 70·3; H,

4·9; N, 7·4. $C_{11}H_9O_2N$ requires C, 70·6; H, 4·9; N, 7·5%). Concentration of the pyridine solution gave a solid (2·73 g.), m. p. 269—273° (decomp.), shown to be identical with the foregoing product by a mixed m. p. and by comparison of infrared spectra. The total yield was 9·41 g. (65%). No other distinct compound was isolated.

The dihydrofuranoquinolone was insoluble in 2N-aqueous sodium hydroxide and was recovered after refluxing with potassium hydroxide in ethanol or with concentrated hydrochloric acid. The compound gave a faint yellow reaction with ferric chloride in ethanol.

2 : 4-*Dichloro*-3-2′-*chloroethylquinoline*.—The dihydrofuranoquinolone (0·5 g.) and phosphorus oxychloride (5 c.c.) were refluxed for 1½ hr. The solid, obtained after removal of the phosphorus oxychloride under reduced pressure and addition of water, separated from ethanol in brown crystals (0·17 g.), which were extracted with ether (100 c.c.). Evaporation of the ether solution gave 2 : 4-*dichloro*-3-2′-*chloroethylquinoline* in colourless rectangular plates (0·12 g.), m. p. 112—114° (Found: C, 50·4; H, 3·6; Cl, 40·7. $C_{11}H_8NCl_3$ requires C, 50·7; H, 3·1; Cl, 40·8%).

1 : 2-*Dihydro*-2-*oxofurano*(3′ : 2′-3 : 4)*quinoline* (VIII; R = H).—The dihydrofuranoquinolone (8 g.), 10% palladium–charcoal (6 g.), and diphenyl ether (50 c.c.) were heated under reflux for 14 hr. The mixture was treated with light petroleum (b. p. 60—80°), and the residue, obtained by filtration, was washed with light petroleum (b. p. 60—80°) and extracted with several portions of boiling ethanol. The combined extract was concentrated to small bulk, and brown crystals of the *furanoquinolone* (4·3 g.), m. p. 234—237°, separated on cooling. A further quantity (0·3 g.) crystallised from the diphenyl ether–light petroleum solution (total yield 4·6 g., 58%). Repeated crystallisation from ethanol (charcoal) gave colourless prisms, m. p. 249—250° (Found: C, 71·3; H, 3·6. $C_{11}H_7O_2N$ requires C, 71·3; H, 3·8%).

The compound was insoluble in 2N-aqueous sodium hydroxide, and gave a faint yellow colour with ferric chloride in ethanol.

1 : 2 : 4′ : 5′-*Tetrahydro*-8-*methoxy*-2-*oxofurano*(3′ : 2′-3 : 4)*quinoline* (VI; R = OMe).—A solution of *o*-anisidine (2·41 g.) and diethyl (2-ethoxyethyl)malonate (5 g.) in diphenyl ether (7 c.c.) was heated at 260° until 3 mols. of ethanol (3 c.c.) were evolved (3 hr.), and allowed to cool. The solid (3·92 g.), m. p. 212—216°, obtained by filtration and washing with light petroleum (b. p. 60—80°), gave the *quinolone* as yellow prisms (2·80 g.), m. p. 219—220° (from pyridine) (Found: C, 66·4; H, 4·9. $C_{12}H_{11}O_3N$ requires C, 66·3; H, 5·1%). Concentration of the pyridine solution afforded a further quantity (0·60 g.) (total yield 3·40 g., 80%). The quinolone was insoluble in 2N-aqueous sodium hydroxide, and gave a faint red colour with ferric chloride in ethanol.

3-2′-*Ethoxyethyl*-2 : 4-*dihydroxy*-8-*methoxyquinoline*.—The foregoing experiment was repeated with *o*-anisidine (4·81 g.), but the heating was discontinued after 2 mols. of ethanol had been obtained (50 min.). Addition of light petroleum (b. p. 60—80°) gave a dark brown oil, yielding a cream-coloured solid (4·2 g.), m. p. 114—117°, by trituration with ether. Crystallisation from ethyl acetate gave the *dihydroxyquinoline* as colourless prisms (1·0 g., 10%), m. p. 130—131° [Found: C, 63·7; H, 6·3; OMe, 23·0. $C_{14}H_{17}O_4N$ requires C, 63·8; H, 6·5; 1OEt + 1OMe (expressed as 2OMe), 23·6%]. This was soluble in 2N-aqueous sodium hydroxide and gave a deep red colour with ferric chloride in ethanol.

1 : 2-*Dihydro*-8-*methoxy*-2-*oxofurano*(3′ : 2′-3 : 4)*quinoline* (VIII; R = OMe).—The corresponding dihydroquinolone (VI; R = OMe) (2·0 g.), 10% palladium–charcoal (0·8 g.), and diphenyl ether (20 c.c.) were heated under reflux, and, after 7 hr., more palladium–charcoal (0·8 g.) was added, and heating was continued for a further 7 hr. On cooling, the solution deposited brown crystals of the *furanoquinolone* (1·80 g.), m. p. 190—193°, crystallising from ethanol in pale yellow prisms (0·66 g., 33%), m. p. 201—203° (Found: C, 66·9; H, 4·6. $C_{12}H_9O_3N$ requires C, 67·0; H, 4·2%). It was insoluble in 2N-aqueous sodium hydroxide and gave a faint red ferric chloride reaction in ethanol.

2-*Chlorofurano*(3′ : 2′-3 : 4)*quinoline* (IX).—A solution of the furanoquinolone (VIII; R = H) (2·25 g.) in phosphorus oxychloride (14 c.c.) was heated under reflux for 1 hr., the excess of reagent was removed under reduced pressure, and the residue was treated with water. The precipitate, on drying at room temperature and crystallising from ethanol (charcoal), afforded colourless needles of 2-*chlorofurano*(3′ : 2′-3 : 4)*quinoline* (1·25 g., 51%), m. p. 118° (Found: C, 64·7; H, 3·2; Cl, 17·3. $C_{11}H_6ONCl$ requires C, 64·9; H, 3·0; Cl, 17·4%).

2-*Methoxyfurano*(3′ : 2′-3 : 4)*quinoline* (II).—The foregoing chloroquinoline (0·10 g.) in methanol (2 c.c.) was refluxed with a solution from sodium (0·10 g.) in methanol (2 c.c.) for 1 hr., and the solution concentrated, diluted with water, and extracted with chloroform. Evaporation of the chloroform gave an oil which was extracted with light petroleum (b. p.

40—60°). Evaporation of the light petroleum and crystallisation of the residue from aqueous ethanol gave 2-*methoxyfurano*(3′ : 2′-3 : 4)*quinoline* as white needles (0·04 g., 41%), m. p. 52—53° (Found : C, 72·3; H, 4·8; OMe, 15·9. $C_{12}H_9O_2N$ requires C, 72·3; H, 4·6; 1OMe, 15·6%).

1 : 2-*Dihydro*-1-*methyl*-2-*oxofurano*(3′ : 2′-3 : 4)*quinoline* (XII).—1 : 2-Dihydro-2-oxofurano-(3′ : 2′-3 : 4)quinoline (0·25 g.), suspended in methanol (10 c.c.), was shaken with methyl sulphate (0·4 c.c.) and methanolic potassium hydroxide (1 c.c.; 20%) for 15 min. Addition of water (4 c.c.) gave a clear solution. After two similar additions of methyl sulphate and alkali at 15-min. intervals, the methanol was removed and the mixture extracted with chloroform. Evaporation of the chloroform gave a red oil which was dissolved in benzene and chromatographed on alumina. Elution with benzene, removal of the solvent, and crystallisation of the residue from light petroleum (b. p. 80—100°) gave colourless needles of the N-*methyl derivative* (0·025 g.), m. p. 129—130° (Found : C, 72·1; H, 4·6; N, 7·0; OMe, 0; *N*-Me, 6·4. $C_{12}H_9O_2N$ requires C, 72·3; H, 4·6; N, 7·0; 1*N*-Me, 7·5%). Elution of the alumina column with benzene–chloroform (2 : 1) gave a further quantity (0·066 g.) (total yield, 0·091 g., 34%). The compound slowly became red on exposure to light.

Elution with chloroform gave a brown solid, crystallising from ethanol in pale brown prisms (0·01 g.), m. p. 241—243°, alone or mixed with the starting materials.

Furano(3′ : 2′-3 : 4)*quinoline* (X).—(*a*) 2-Chlorofurano(3′ : 2′-3 : 4)quinoline (0·50 g.), 90% hydrazine hydrate (0·4 c.c.), and ethanol (3 c.c.) were heated under reflux for 3 hr., and then evaporated to dryness under reduced pressure. The residue, when treated with water, gave a yellow solid (0·49 g.), m. p. 120°, probably consisting of the hydrazine derivative. The solid was suspended in boiling water (20 c.c.), boiling 10% aqueous copper sulphate (20 c.c.) was added, and the mixture was refluxed for 1 hr. Pale yellow crystals (*ca.* 5 mg.), which distilled in steam from the mixture, proved to be 2-chlorofurano(3′ : 2′-3 : 4)quinoline (m. p. and mixed m. p. 112—113°). The solution was made alkaline with 2N-sodium hydroxide, and extracted with chloroform. Evaporation of the chloroform and distillation of the residue (0·28 g.) gave the *furanoquinoline* as a pale yellow oil, b. p. 130—140° (bath)/0·6 mm., crystallising from light petroleum (b. p. 40—60°) in colourless needles (0·25 g., 62%), m. p. 36—37° (Found : C, 77·9; H, 4·2; N, 8·5. $C_{11}H_7ON$ requires C, 78·1; H, 4·2; N, 8·3%).

(*b*) A mixture of the chlorofuranoquinoline (0·5 g.), zinc dust (6·7 g.), ethanol (10 c.c.), and 2N-sulphuric acid (10 c.c.) was shaken for 2 hr., then extracted with ether. Evaporation of the ether gave only a trace of material. After the solution had been made alkaline with aqueous sodium hydroxide, ether-extraction, evaporation of the ether, and distillation of the residue gave a pale yellow oil (26 mg., 6%), b. p. 150—160° (bath)/0·03 mm., shown by comparison of infrared spectra to be identical with furano(3′ : 2′-3 : 4)quinoline obtained as in (*a*).

Potassium Permanganate Oxidation of Furano(3′ : 2′-3 : 4)*quinoline.*—Potassium permanganate (1·5 g.) in acetone (54 c.c.) was added during 1½ hr. to a solution of the furanoquinoline (0·674 g.) in acetone (10 c.c.). After addition of water, the solution was clarified with sulphur dioxide, the acetone removed, and the solution was made alkaline with sodium hydrogen carbonate and extracted with chloroform to remove traces of unchanged furanoquinoline. Acidification of the alkaline solution precipitated 3-carboxy-4-quinolone (0·127 g., 17%), m. p. 269—270° (decomp.), crystallising from ethanol in colourless needles, m. p. 265—266° (decomp.), and shown to be identical with an authentic sample [prepared by the Price–Roberts method (Riegel, Lappin, Adelson, Jackson, Albisetti, Dodson, and Baker, *J. Amer. Chem. Soc.*, 1946, **68**, 1264)] by a mixed m. p. and by comparison of infrared spectra (Found : C, 63·2; H, 3·6; N, 7·1. Calc. for $C_{10}H_7O_3N$: C, 63·5; H, 3·7; N, 7·4%).

3-*Ethoxycarbonyl*-2 : 4-*dihydroxyquinoline* (cf. Brown *et al.*, *loc. cit.*).—Methyl anthranilate (60 g.) and diethyl malonate (330 g.) were heated at 195° until 1 mol. of ethanol had been evolved (3 hr.). The crude monoamide, obtained by removal of excess of diethyl malonate, was cyclised in refluxing ether (300 c.c.) by dropwise addition of a solution of sodium (10 g.) in ethanol (180 c.c.). After 12 hr. at room temperature, the precipitate was removed and dissolved in water (1 l.). Acidification with hydrochloric acid gave the dihydroxy-ester, crystallising from ethanol in colourless needles (57·5 g., 62%), m. p. 208° (Found : C, 61·8; H, 4·8; N, 6·2. Calc. for $C_{12}H_{11}O_4N$: C, 61·8; H, 4·8; N, 6·1%).

3-*Ethoxycarbonyl*-4-*methoxy*-2-*quinolone.*—3-Ethoxycarbonyl-2 : 4-dihydroxyquinoline (3 g.), suspended in ether (25 c.c.), was treated with excess of ethereal diazomethane. After 12 hr. the solid present was removed and the solution concentrated to small bulk, more solid separating. The combined precipitate of the methoxyquinoline (1·6 g., 50%), m. p. 135—141°, crystallised from aqueous methanol in colourless plates, m. p. 144° [Found : C, 63·3; H, 5·2; N, 6·1; OMe, 24·0. Calc. for $C_{13}H_{13}O_4N$: C, 63·2; H, 5·3; N, 5·7; 1OMe + 1OEt (expressed as

2OMe), 25·1%]. Brown *et al.* (*loc. cit.*) were only able to obtain this product by adding methanol to the ether solution.

2 : 4-*Dichloro-3-ethoxycarbonylquinoline.*—3-Ethoxycarbonyl-2 : 4-dihydroxyquinoline (1 g.) and phosphorus oxychloride (12 c.c.) were heated under reflux for 1½ hr. After removal of the phosphorus oxychloride under reduced pressure, addition of water gave the *dichloro-compound* (1·1 g., 95%), m. p. 103—104°, crystallising from aqueous ethanol in colourless rectangular plates, m. p. 104° (Found: C, 53·4; H, 3·6. $C_{12}H_9O_2NCl_2$ requires C, 53·4; H, 3·4%).

3-Carboxy-2-chloro-4-methoxyquinoline (XIV; R = H).—A solution of 3-ethoxycarbonyl-4-methoxy-2-quinolone (2 g.) in phosphorus oxychloride (10 c.c.) was refluxed for 20 min. After removal of the oxychloride under reduced pressure, water (50 c.c.) was added, and the mixture was extracted with ether (3 × 30 c.c.). The ether solution was washed with aqueous sodium carbonate and water, dried, and evaporated. Trituration of the oily residue with ether (10 c.c.) gave 3-ethoxycarbonyl-4-methoxy-2-quinolone (0·22 g.), m. p. and mixed m. p. 142—143°. The ether solution was evaporated, and the residue dissolved in ethanol (10 c.c.) giving a solid (0·47 g.), m. p. 90—96°, which crystallised from ethanol in colourless rectangular plates, m. p. 103—104°, alone or mixed with 2 : 4-dichloro-3-ethoxycarbonylquinoline.

Evaporation of the ethanol solution gave crude 2-chloro-3-ethoxycarbonyl-4-methoxyquinoline as a colourless oil (0·96 g.). A sample was distilled [b. p. 170—175° (bath)/0·2 mm.] [Found: C, 57·7; H, 4·0; Cl, 15·2; OMe, 17·8. Calc. for $C_{13}H_{12}O_3NCl$: C, 58·8; H, 4·6; Cl, 13·4; 1OMe + 1OEt (expressed as 2OMe), 23·4. Calc. for $C_{12}H_9O_2NCl_2$: C, 53·4; H, 3·4; Cl, 20·8; 1OEt (expressed as 1OMe), 11·5%]. The analysis indicated that the product was contaminated with 2 : 4-dichloro-3-ethoxycarbonylquinoline.

A solution of crude 2-chloro-3-ethoxycarbonyl-4-methoxyquinoline (0·40 g.) in methanol (10 c.c.) was heated with 15% aqueous potassium hydroxide (10 c.c.) on a steam-bath for 10 min., and the methanol removed under reduced pressure. Acidification with hydrochloric acid gave a semi-solid precipitate, which, by crystallisation from methanol, yielded *3-carboxy-2-chloro-4-methoxyquinoline* as colourless plates (0·09 g.), m. p. 173—175° (decomp.) (Found: C, 55·4; H, 3·5; OMe, 13·1. $C_{11}H_8O_3NCl$ requires C, 55·6; H, 3·4; OMe, 13·1%). This dissolved in aqueous sodium hydrogen carbonate, and gave no colour with ferric chloride in aqueous ethanol.

3-Carboxy-2-chloro-4-quinolone (XV; R = Cl).—A solution of 3-carboxy-2-chloro-4-methoxyquinoline (0·075 g.) in 15% aqueous potassium hydroxide (5 c.c.) was heated on a steam-bath for 30 min. The acid, obtained by acidification with hydrochloric acid, separated from methanol in colourless needles (0·055 g.), m. p. 184—186° (decomp.), raised by recrystallisation from methanol to 194—195° (decomp.) [Brown *et al.* (*loc. cit.*) report m. p. 196° (decomp.)] (Found: C, 54·0; H, 2·7. Calc. for $C_{10}H_6O_3NCl$: C, 53·7; H, 2·7%), and gave a red-brown colour with ferric chloride in aqueous ethanol.

3-Carboxy-2-hydrazino-4-quinolone (XV; R = $NH{\cdot}NH_2$).—A solution of 3-carboxy-2-chloro-4-quinolone (0·09 g.) in ethanol (20 c.c.) containing 90% hydrazine hydrate (0·5 c.c.) was heated on a steam-bath. After 15 min. white needles began to separate, and after a further 2 hr. the *hydrazino-compound* (0·08 g., 90%), m. p. 216—217° (decomp.), was collected; it separated from acetic acid in colourless needles, m. p. 224° (decomp.) (Found: C, 55·0; H, 4·3; N, 18·9. $C_{10}H_9O_3N_3$ requires C, 54·8; H, 4·1; N, 19·2%).

Reduction of 3-Carboxy-2-hydrazino-4-quinolone.—The hydrazino-derivative (0·08 g.), suspended in boiling water (10 c.c.), was treated with 10% aqueous copper sulphate (2 c.c.), and the mixture was refluxed for 1 hr. 2N-Sodium hydroxide (5 c.c.) was added, and heating was continued for a further 15 min. The cold, filtered solution was acidified with hydrochloric acid. The precipitate of 3-carboxy-4-quinolone (0·06 g., 87%) crystallised from ethanol or acetic acid in colourless needles, m. p. 264—266° (decomp.), shown by a mixed m. p. and by comparison of infrared spectra to be identical with an authentic sample (Found: C, 63·3; H, 3·6; N, 7·4. Calc. for $C_{10}H_7O_3N$: C, 63·5; H, 3·7; N, 7·4%).

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Fluoro-olefins. Part IV. Synthesis of Polyfluoroalkanes containing Functional Groups from Chlorotrifluoroethylene, and the Short-chain Polymerisation of Olefins.†*

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The photochemical reaction of $CF_2Cl{\cdot}CFClI$ with chlorotrifluoroethylene yields compounds of general formula $Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}I$; those with $n = 1$—11 have been isolated. The iodine can easily be replaced by chlorine to give compounds $Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}Cl$ which show high chemical and thermal stability. The terminal $CF_2Cl{\cdot}CFCl$ group can be converted into $CF_2{:}CF$, which can then undergo addition reactions such as formation of sulphonic acids $Cl{\cdot}[CFCl{\cdot}CF_2]_{n-1}{\cdot}CHF{\cdot}CF_2{\cdot}SO_3H$, and can be oxidised to give long-chain acids $Cl{\cdot}[CFCl{\cdot}CF_2]_{n-1}{\cdot}CO_2H$. Photochemical oxidation of the $-CFClI$ group in $Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}I$ gives $Cl{\cdot}[CF_2{\cdot}CFCl]_{n-1}{\cdot}CF_2{\cdot}CO_2H$. Reactions of the salts of these acids are described. The factors which affect the short-chain polymerisation of fluoro-olefins are considered.

The development of a chemistry based upon perfluorocarbons as parent compounds, just as hydrocarbons are regarded as parent compounds in organic chemistry, can follow two main paths, (*a*) conversion of an organic compound containing a functional group into the corresponding perfluoro-compound and (*b*) synthesis of the polyfluoro-compound from smaller molecules. The replacement of hydrogen by fluorine in a compound which already contains the functional group can be achieved only to a limited extent by direct fluorination or by use of cobaltic fluoride, since loss of the functional group usually occurs with formation of the perfluorocarbon from the resulting fragment. Electrolysis of an organic compound in anhydrous hydrogen fluoride leads in certain cases to formation of the perfluoro-compound which still retains the functional group, *e.g.*, the electrolysis of derivatives of carboxylic acids to give perfluoroacyl fluorides (U.S.P. 2,593,737/1951) and the electrolysis of alkanesulphonyl fluorides or chlorides to give perfluoroalkanesulphonyl fluorides almost quantitatively (Gramstad and Haszeldine, *J.*, in the press). Even with this improved technique, replacement of hydrogen by fluorine in a long-chain compound is often accompanied by excessive breakdown and formation of a complex mixture of products. The approach which involves replacement of hydrogen by fluorine is thus best suited for preparation of short-chain compounds.

The second approach is to build up a polyfluorocarbon chain by controlled polymerisation of a suitable relatively cheap polyhalogeno-olefin, yet leaving an atom or group at the end or ends of the chain which can be easily converted into a suitable functional group. This approach, which is potentially the more versatile, has been exemplified by the synthesis of compounds $CF_3{\cdot}[CF_2{\cdot}CF_2]_n{\cdot}I$ from tetrafluoroethylene and trifluoroiodomethane (Haszeldine, *J.*, 1949, 2856; 1953, 3761), since the value of n can be controlled and the C–I bond can be made to undergo a wide variety of reactions, *e.g.*, replacement by $-MgI$, $-CO_2H$, $-PO_3H$, or $-CF{:}CF_2$ as reported earlier (see Haszeldine, *Ann. Reports*, 1954, **51**, 279, for references).

The second approach has now been studied further by use of chlorotrifluoroethylene as the olefin and 1 : 2-dichloro-1 : 2 : 2-trifluoroiodoethane (I) as the source of polyfluoroalkyl radical. The value of the fluoroethane (I) lies in its ease of preparation from chlorotrifluoroethylene and iodine monochloride (Part I, *J.*, 1952, 4423) and in its ready conversion after reaction into a $CF_2{:}CF-$ group which is thus attached at the end of a polyfluoroalkane chain and is available for subsequent reaction, *e.g.*, by oxidation to give $-CO_2H$, or by addition to give $-CHF{\cdot}CF_2{\cdot}SO_3H$.

Commercially available chlorotrifluoroethylene can be polymerised to a solid high polymer. Miller, Dittman, Ehrenfeld, and Probe (*Ind. Eng. Chem.*, 1947, **39**, 333)

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described the preparation of oils and waxes from chlorotrifluoroethylene by use of benzoyl peroxide in chloroform, but such products contain C_6H_5, $C_6H_5{\cdot}CO{\cdot}O$, $CHCl_2$, or CCl_3 end groups which cause instability and necessitate further treatment to replace hydrogen or chlorine in the end groups by fluorine. During this step appreciable loss of material occurs. Furthermore, the products so obtained cannot be used for further synthesis, since they contain no potential functional group.

1 : 2-Dichloro-1 : 2 : 2-trifluoroiodoethane reacts smoothly with chlorotrifluoroethylene under the influence of ultraviolet light or heat or a combination of the two, to give products $Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}I$ produced by a free-radical chain reaction :

$$\text{(I)}\quad CF_2Cl{\cdot}CFClI \xrightarrow{h\nu} CF_2Cl{\cdot}CFCl{\cdot} + I{\cdot}$$

$$CF_2Cl{\cdot}CFCl{\cdot} + CF_2{:}CFCl \longrightarrow CF_2Cl{\cdot}CFCl{\cdot}CF_2{\cdot}CFCl{\cdot} \quad \text{Initiation}$$

$$CF_2Cl{\cdot}CFCl{\cdot}CF_2{\cdot}CFCl{\cdot} + CF_2{:}CFCl \longrightarrow Cl{\cdot}[CF_2{\cdot}CFCl]_2{\cdot}CF_2{\cdot}CFCl{\cdot} \quad \text{Propagation}$$

$$CF_2Cl{\cdot}CFCl{\cdot}CF_2{\cdot}CFCl{\cdot} + CF_2Cl{\cdot}CFClI \longrightarrow CF_2Cl{\cdot}CFCl{\cdot}CF_2{\cdot}CFClI + CF_2Cl{\cdot}CFCl{\cdot} \longrightarrow \text{etc.}$$

Chain Transfer

Peroxide initiators could clearly be used for this reaction on a larger scale. As demonstrated for the reaction of trifluoroiodomethane with tetrafluoroethylene (*J.*, 1953, 3761), the main factors which determine n in $Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}I$ are the relative concentrations of the chain-transfer agent (I), the monomer (*i.e.*, chlorotrifluoroethylene), and the growing polymer radical. A high ratio of the chain-transfer agent to chlorotrifluoroethylene enables the $CF_2Cl{\cdot}CFCl{\cdot}CF_2{\cdot}CFCl{\cdot}$ radical, produced by the initial reaction of the $CF_2Cl{\cdot}CFCl{\cdot}$ radical with the olefin, to react with 1 : 2-dichloro-1 : 2 : 2-trifluoroiodoethane (I) rather than with chlorotrifluoroethylene, and so produce 1 : 2 : 4-trichlorohexafluoro-4-iodobutane (II) with regeneration of a $CF_2Cl{\cdot}CFCl{\cdot}$ radical. This chain transfer is best effected in the liquid phase where the concentration of the fluoroethane (I) is at a maximum. Use of a ratio of 15 : 1 gives a 75% yield of the compound (II).

$$\text{(II)}\quad CF_2Cl{\cdot}CFCl{\cdot}CF_2{\cdot}CFClI \qquad CF_2Cl{\cdot}CFCl{\cdot}CF_2{\cdot}CFCl_2 \quad \text{(III)}$$

Irradiation of equimolar quantities of 1 : 2-dichloro-1 : 2 : 2-trifluoroiodoethane and the olefin gives compounds $Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}I$ in the following yields: $n = 2$, 18%; $n = 3$, 14%; $n = 4$, 17%; $n > 4$, 39%. Use of an excess of chlorotrifluoroethylene gives a wider spread of products with consequently more difficulty in separation of individual members of the polymer series.

Each member of the series $Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}I$ contains a CFClI group and has properties similar to those of $CF_2Cl{\cdot}CFClI$. The ratio of the amount of the latter to that of polymeric product $Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}I$ at any instant must thus be high, otherwise further reaction of chlorotrifluoroethylene with the polymer already formed will occur :

$$Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}I \xrightarrow[h\nu]{m CF_2{:}CFCl} Cl{\cdot}[CF_2{\cdot}CFCl]_{(m+n)}{\cdot}I$$

and increased spread in the value of n will result. The optimum method for the synthesis of any given longer-chain iodo-compound is thus to proceed stepwise using an excess of the chain-transfer agent, since a compound $Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}I$ can be converted into $Cl{\cdot}[CF_2{\cdot}CFCl]_{(n+1)}{\cdot}I$ in high yield under these conditions, *e.g.*,

$$Cl{\cdot}[CF_2{\cdot}CFCl]_2{\cdot}I \xrightarrow{CF_2{:}CFCl} Cl{\cdot}[CF_2{\cdot}CFCl]_3{\cdot}I \xrightarrow{CF_2{:}CFCl} Cl{\cdot}[CF_2{\cdot}CFCl]_4{\cdot}I \longrightarrow \text{etc.}$$

where the compounds $Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}I$ with $n = 2$, 3, 4, etc., are used successively as chain-transfer agents.

The compounds $Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}I$ remain liquid to a greater value of n than the corresponding compounds $CF_3{\cdot}[CF_2{\cdot}CF_2]_n{\cdot}I$, but when n is greater than 20 waxes and solids are obtained which resemble poly(chlorotrifluoroethylene) and poly(tetrafluoroethylene) in appearance.

The C–I bond in a –CFClI group is appreciably weaker than that in trifluoroiodomethane. This is attributed to steric repulsion caused by the chlorine atom, and is reflected in the

ultraviolet spectra of compounds which contain this group (cf. $CF_3{\cdot}CF_2{\cdot}CF_2I$, $\lambda_{max.}$ 271 mμ; $CF_3{\cdot}CF_2{\cdot}CFClI$, $\lambda_{max.}$ 286 mμ; $CF_2Cl{\cdot}CF_2I$, $\lambda_{max.}$ 272 mμ; $CF_2Cl{\cdot}CFClI$, $\lambda_{max.}$ 283 mμ in light petroleum: see Haszeldine, *J.*, 1953, 1764; Haszeldine and Steele, *J.*, 1953, 1592, for interpretation of the spectra). This means that photolysis of the C–I bond in 1 : 2-dichloro-1 : 2 : 2-trifluoroiodoethane is particularly easy and that the chain transfer step is particularly efficient. The reaction of 1 : 2-dichloro-1 : 2 : 2-trifluoroiodoethane with chlorotrifluoroethylene is thus more easily controlled than that between trifluoroiodomethane and tetrafluoroethylene, and the compounds $Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}I$ where $n = 2$—20 are readily produced. These compounds contain a CF_2 group adjacent to the terminal CFClI group, and this makes them appreciably more stable to distillation than the dichlorotrifluoroiodoethane, which has a CF_2Cl group next to the CFClI group and tends to lose iodine monochloride when heated. The compounds are very sensitive to oxygen which must be rigidly excluded during distillation if breakdown is to be avoided. Exposure of the crude polymer to air before distillation appears to cause formation of peroxides, since decomposition during distillation is then much more marked and the higher members of the series cannot be obtained pure.

The possibility of radical combination's occurring during the polymerisation can be excluded for the shorter-chain polymer, but material of this type might be present to a small extent in the polymer of higher molecular weight.

Free radicals were unambiguously shown to add exclusively to the CF_2 group of chlorotrifluoroethylene by earlier studies (Haszeldine and Steele, *J.*, 1953, 1592; 1954, 3747), where it was also shown that poly(chlorotrifluoroethylene) is formed by head-to-tail addition; it is thus highly probable that the $CF_2Cl{\cdot}CFCl$ radical attacks the CF_2 group of chlorotrifluoroethylene. This was rigidly proved by study of 1 : 2 : 4-trichlorohexafluoro-4-iodobutane (II), photochemical chlorination of which gives 1 : 1 : 3 : 4-tetrachlorohexafluorobutane (III). This product is isomeric with 1 : 2 : 3 : 4-tetrachlorohexafluorobutane (IV) which would be produced if the $CF_2Cl{\cdot}CFCl$ radical attacked the CFCl group of chlorotrifluoroethylene:

$$CF_2Cl{\cdot}CFCl\cdot \xrightarrow{CF_2{:}CFCl} CF_2Cl{\cdot}CFCl{\cdot}CFCl{\cdot}CF_2\cdot \xrightarrow{CF_2Cl{\cdot}CFClI} CF_2Cl{\cdot}CFCl{\cdot}CFCl{\cdot}CF_2I \xrightarrow[h\nu]{Cl_2} (CF_2Cl{\cdot}CFCl)_2$$
(IV)

The absence of even traces of compound (IV) in the photochemical chlorination product was shown by reaction with zinc and ethanol, which failed to yield hexafluorobutadiene; this conversion is known to occur in high yield under the conditions used (Part I, *loc. cit.*) and the diene is readily detectable even in small amount by means of its infrared spectrum. Attack of the $CF_2Cl{\cdot}CFCl$ radical is thus exclusively on the CF_2 group of chlorotrifluoroethylene.

1 : 1 : 3 : 4-Tetrachlorohexafluorobutane (III) reacts with zinc and ethanol under mild conditions to give 4 : 4-dichlorohexafluorobut-1-ene (V), which is isomeric with the 1 : 4-dichlorohexafluorobut-2-ene described in Part I (*loc. cit.*). Photochemical chlorination

$CF_2{:}CF{\cdot}CF_2{\cdot}CFCl_2$ (V) $\qquad$ $CF_2Br{\cdot}CFBr{\cdot}CF_2{\cdot}CFCl_2$ (VI) $\qquad$ $CFCl_2{\cdot}CF_2{\cdot}CO_2H$ (VII)

regenerates 1 : 1 : 3 : 4-tetrachlorohexafluorobutane, and bromination similarly gives 1 : 2-dibromo-4 : 4-dichlorohexafluorobutane (VI). Permanganate oxidation of the butene (V) must be carried out with control of pH to prevent complete breakdown. ββ-Dichlorotrifluoropropionic acid (VII) is formed in good yield. Pyrolysis of its anhydrous silver salt causes breakdown to silver chloride, etc., instead of the coupling to give $(CFCl_2{\cdot}CF_2)_2$ which might have been expected by analogy with silver perfluoropropionate which gives perfluorobutane (*J.*, 1953, 1548). The silver salt reacts smoothly with chlorine, however, and pyrolysis of anhydrous sodium 3 : 3-dichlorotrifluoropropionate also proceeds as expected:

$$CFCl_2{\cdot}CF_2{\cdot}CO_2Ag + Cl_2 \longrightarrow CFCl_2{\cdot}CF_2Cl + CO_2 + AgCl$$

$$CFCl_2{\cdot}CF_2{\cdot}CO_2Na \longrightarrow Cl{-}CFCl{-}CF_2^- \longrightarrow CFCl{:}CF_2 + Cl^-$$

Application of the silver- and sodium-salt degradation reactions to chloropolyfluoro-acids as well as to perfluoro-mono- and -di-basic acids (*J.*, 1951, 584; 1952, 993; 1954, 4026) was demonstrated recently (Part III, *loc. cit.*) and is here illustrated further. It will be noted that olefin formation is accompanied by loss of chlorine rather than fluorine. The formation of 1 : 1 : 2-trichlorotrifluoroethane and chlorotrifluoroethylene in good yield by the above reactions proves the structure of the acid (VII), and hence of the butene (V) and the butanes (III) and (II).

The constitution of the longer-chain members of the $Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}I$ series will clearly follow that of the compound where $n = 2$. This is supported by the ultraviolet spectra shown in Table 1, which reveal the –CFClI chromophore.

TABLE 1. *Ultraviolet spectra of* $Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}I$ *in light petroleum* (b. p. 60—80°).

n	$\lambda_{max.}$	ε	$\lambda_{min.}$	ε	n	$\lambda_{max.}$	ε	$\lambda_{min.}$	ε
1	283	315	229	25	7	293·5	350	240	70
2	286·5	320	231	35	8	293·5	345	241	70
3	291	330	238·5	50	9	294	355	242	75
4	291·5	335	237·5	60	10	294	360	242	80
5	292	345	240	65	16—18		$\lambda_{max.}$ 294 mμ		
6	293	345	242	65	20 (average)		$\lambda_{max.}$ 290 mμ in $CHCl_3$		

The –CFClI chromophore shows maximum absorption at 286 mμ, shifting to 294 mμ with increase in chain length (*J.*, 1953, 1592, 1764) whereas the $-CF_2I$ chromophore absorbs at 271—272 mμ (*J.*, 1953, 1764, 3761) for solutions in light petroleum. Increase in chain length in $Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}I$ thus causes a distinct shift toward the red of 10 mμ, and there is little change in the spectrum when $n > 4$. The material which has an average value of $n = 20$ is insufficiently soluble in light petroleum, but chloroform dissolves it readily.

The polymer series $Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}I$ reacts smoothly with chlorine to give $Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}Cl$, particularly if an inert diluent is used with the more viscous compounds. These compounds show great thermal and chemical stability approaching that of poly(chlorotrifluoroethylene). There is no point of weakness for chemical attack, since the end groups are CF_2Cl and $CFCl_2$. The compounds range from liquids through thin oils, viscous oils, and waxes, to solids. Replacement of iodine by chlorine in a polymer fraction which contains a range of values for n gives a product which remains an oil despite the fact that individual members of the mixtures are waxes or solids. Such mixtures can be used as lubricants or as thermally stable liquids, and this method of preparation of polyfluoro-oils is better than any so far devised, since end-group stabilisation is achieved simply yet efficiently and without loss of material or use of powerful fluorinating agents. The thermal stability of the compounds $Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}Cl$ makes their separation by distillation easier, and the compounds with $n = 1$—8 have thus been isolated.

The iodine in $Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}I$ can be replaced by fluorine by use of reagents such as bromine or chlorine trifluoride (*e.g.*, $CF_2Cl{\cdot}CFCl{\cdot}CF_2{\cdot}CFClI \longrightarrow CF_2Cl{\cdot}CFCl{\cdot}CF_2{\cdot}CF_2Cl$).

Reaction of $Cl{\cdot}[CF_2{\cdot}CFCl]_3{\cdot}Cl$ with zinc and ethanol under mild conditions gives the olefin (VIII):

$$CF_2Cl{\cdot}CFCl{\cdot}CF_2{\cdot}CFCl{\cdot}CF_2{\cdot}CFCl{\cdot}CF_2Cl \longrightarrow CF_2{:}CF{\cdot}CF_2{\cdot}CFCl{\cdot}CF_2{\cdot}CFCl{\cdot}CF_2Cl \quad \text{(VIII)}$$

and this type of reaction can be applied to the longer-chain compounds to give $CF_2{:}CF{\cdot}[CF_2{\cdot}CFCl]_m{\cdot}Cl$. The structure of the olefin (VIII) follows from the reactions of the monocarboxylic acid obtained by permanganate oxidation in presence of sodium hydrogen carbonate. Pyrolysis of the anhydrous sodium salt gives 4 : 4-dichlorohexafluorobut-1-ene (V), identical with the compound described above:

$$\text{(VIII)} \xrightarrow{KMnO_4} CFCl_2{\cdot}CF_2{\cdot}CFCl{\cdot}CF_2{\cdot}CO_2H \longrightarrow CFCl_2{\cdot}CF_2{\cdot}CFCl{\cdot}CF_2{\cdot}CO_2Na$$

$$CFCl_2{\cdot}CF_2{\cdot}CFCl{\cdot}CF_2{\cdot}CO_2Na \longrightarrow CFCl_2{\cdot}CF_2{\cdot}CFCl{\cdot}CF_2^- + CO_2 + Na^+$$

$$Cl{-}CF{-}CF_2^- \longrightarrow CFCl_2{\cdot}CF_2{\cdot}CF{:}CF_2 + Cl^-$$

$$\quad\quad CF{\cdot}CFCl_2$$

Reaction of the silver salt of the acid similarly gave 1 : 1 : 3 : 4-tetrachlorohexafluorobutane (III) :

$$CFCl_2{\cdot}CF_2{\cdot}CFCl{\cdot}CF_2{\cdot}CO_2Ag + Cl_2 \longrightarrow CFCl_2{\cdot}CF_2{\cdot}CFCl{\cdot}CF_2Cl + AgCl + CO_2$$

The olefins $CF_2{:}CF{\cdot}[CF_2{\cdot}CFCl]_m{\cdot}Cl$ can be used to give other compounds which contain functional groups. Peroxide-initiated reaction with sodium hydrogen sulphite thus yields sulphonic acids :

$$Cl{\cdot}[CFCl{\cdot}CF_2]_m{\cdot}CF{:}CF_2 \xrightarrow{NaHSO_3} Cl{\cdot}[CFCl{\cdot}CF_2]_m{\cdot}CHF{\cdot}CF_2{\cdot}SO_3Na$$

this is illustrated by preparation of the compounds where $m = 1$ or 2. Barrick (U.S.P. 2,403,207/1946) first showed that tetrafluoroethylene reacted with sodium hydrogen sulphite to give tetrafluoroethanesulphonic acid, and Koshar, Trott, and LaZerte (*J. Amer. Chem. Soc.*, 1953, **75**, 4595) have recently extended this to the reactions of longer-chain terminal perfluoro-olefins. The longer-chain polychloropolyfluoroalkanesulphonic acids are strong acids which are readily soluble in water and liberate hydrogen chloride from sodium chloride. They show distinct surface activity in aqueous solution.

Photochemical oxidation of 1-chlorohexafluoro-1-iodopropane in presence of water gives pentafluoropropionic acid in high yield ($C_2F_5{\cdot}CFClI \xrightarrow{O_2,\,h\nu} C_2F_5{\cdot}COF \xrightarrow{H_2O} C_2F_5{\cdot}CO_2H$; Francis and Haszeldine, *J.*, 1955, 2151). This useful general method for the preparation of polyfluoro-acids has been applied to the compounds $Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}CF_2{\cdot}CFClI$ to give satisfactory yields of long-chain polyfluoro-acids. On a small scale ultraviolet light can be used to cleave the C–I bond to initiate the radical chain reaction leading to the formation of the polyfluoroalkoxy-radical, but on a larger scale thermal cleavage of the C–I bond, or abstraction of iodine by a radical generated from an added peroxide such as benzoyl peroxide can be used in absence of light. This permits use of conventional equipment such as autoclaves :

$$Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}CF_2{\cdot}CFClI \xrightarrow{h\nu\ (\text{or } Ph\cdot)} Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}CF_2{\cdot}CFCl\cdot + I\cdot\ (\text{or } PhI)$$

$$\downarrow O_2$$

$$Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}CF_2{\cdot}CFCl{\cdot}O_2\cdot$$

$$Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}CF_2{\cdot}CFCl{\cdot}O_2\cdot + Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}CF_2{\cdot}CFClI \longrightarrow Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}CF_2{\cdot}CFCl{\cdot}O_2{\cdot}I$$

$$+ Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}CF_2{\cdot}CFCl\cdot \xrightarrow{O_2} \text{etc.}$$

$$Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}CF_2{\cdot}CFCl{\cdot}O_2{\cdot}I \longrightarrow Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}CF_2{\cdot}CFCl{\cdot}O\cdot + \cdot OI \longrightarrow \text{etc.}$$

$$Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}CF_2{\cdot}CFClO\cdot \longrightarrow Cl\cdot + Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}CF_2{\cdot}COF \longrightarrow Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}CF_2{\cdot}CO_2H$$

The long-chain acids obtained contain a terminal $CF_2{\cdot}CO_2H$ group and are thus as strong as the perfluoro-carboxylic acids and markedly surface-active. This route to long-chain acids is simpler than that which involves electrochemical fluorination. Polyfluoro-acids can thus be prepared by attack at either end of the $Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}I$ chain, and dicarboxylic acids can be prepared by photochemical oxidation of $I{\cdot}[CFCl{\cdot}CF_2{\cdot}]_n{\cdot}CO_2H$.

The present study thus demonstrates that polyfluoroalkanes with reactive end groups capable of use in further synthesis can be obtained from chlorotrifluoroethylene without use of expensive chemicals, compounds such as trifluoroiodomethane, or electrochemical fluorination. The iodine in the polymer is present only as end group, and makes available the further syntheses of compounds containing such terminal groups as MgI, SO_3H, PO_3H, NO, NO_2, SH by processes described earlier for polyfluoroiodoalkanes.

Factors affecting the Short-chain Polymerisation of Fluoro-olefins.—The studies on the short-chain polymerisation of a fluoro-olefin with a compound R·CFXY to give R·CFX·[fluoro-olefin]$_n$·Y which have been reported above and in earlier papers lead to several general observations and predictions on the factors affecting such reactions. The conclusions reached can be applied to all reactions of this type (sometimes referred to as " telomerisation " reactions).

(*a*) *Initiation step.* Initiation is usually achieved by use of a polyhalogenoalkyl radical (*e.g.*, $CF_3\cdot$, $CF_2Cl\cdot CFCl\cdot$) but is not restricted to this, since a bromine atom (*J.*, **1954**, **3747**) can also be used. Two distinct stages are involved in the initiation step: generation of the initiating radical, and its reaction with the olefin. The rate of generation of the initiating R·CFX· radical from a compound R·CFXY (in a typical case R = polyhalogenoalkyl, or F; X = halogen or hydrogen; Y = halogen usually different from X and of higher atomic weight) depends on the following three factors:

(i) The strength of the C–Y bond and hence the stability of the R·CFX· free radical; the weaker C–Y, the greater the ease of generation of R·CFX·. The nature of both Y and X determines the C–Y bond strength, which decreases in the series Y = F > Cl > Br > I for a given X, and which can be predicted, with reasonable certainty, to decrease in the series $R\cdot CF_2{-}Y$ (Y = F) > $R\cdot CF_2{-}Y$ (Y = Cl) > R·CHF–Y (Y = Cl) > R·CFCl–Y (Y = Cl) > $R\cdot CF_2{-}Y$ (Y = Br) > R·CHF–Y (Y = Br) > R·CFCl–Y (Y = Br) > R·CFBr–Y (Y = Br) > $R\cdot CF_2{-}Y$ (Y = I) > R·CHF–Y (Y = I) > R·CFCl–Y (Y = I) > R·CFBr–Y (Y = I) > R·CFI–Y (Y = I). The reason for the effect of X on the C–Y bond energy has been discussed earlier (Haszeldine, *J.*, **1953**, **1764**) and is associated with the stability of the R·CFX· free radical and with the increase in steric strain between X and Y as X becomes larger. The change in C–Y bond energy is readily seen when Y = I or Br by use of ultraviolet spectra (*J.*, **1953**, **1764**; and unpublished data).

(ii) The physical conditions, *e.g.*, the intensity of ultraviolet light and/or the temperature which provide the energy for C–Y fission.

(iii) The concentration of peroxide if a peroxide is used instead of, or in combination with, light or heat to cause C–Y fission.

Generation of the R·CFX· radical must be followed by the second stage of the initiation reaction, *i.e.*, attack on the olefin. The ease of this reaction depends mainly upon the reactivity of the olefin and to a lesser extent on the reactivity of the attacking radical R·CFX·. In general, halogen bonded to the doubly-bonded carbon atoms, or to carbon atoms adjacent to the doubly-bonded carbon atoms in an olefin containing more than three carbon atoms, decreases the ease of free-radical attack relative to the corresponding unsubstituted olefin (*J.*, **1952**, **2504**; **1953**, **1199**, **1592**, **3559**, **3565**; **1955**, **3005**). Halogenoethylenes are special cases, since the polyfluoro- and chloropolyfluoro-ethylenes polymerise readily; in general, the greater the atomic weight of the halogen in a halogenoethylene, and the more symmetrically the halogen is distributed (cf. $CF_2{:}CCl_2$ and CFCl:CFCl), the less readily does the olefin polymerise, and the less readily is it attacked by a free radical.

The reactivity of R·CFX· is seldom of sufficient importance to be decisive in polymerisations of the type under discussion, since the more reactive olefins readily combine with even the least reactive radicals. It is only with olefins heavily or symmetrically substituted by halogen such as chlorine or bromine, or in which steric inhibition of radical attack occurs, that the less reactive radicals fail to add and more reactive radicals (*e.g.*, X in R·CFX· = H, F, or Cl) must be used.

(*b*) *Propagation.* The efficiency of the propagation step

$$R\cdot CFX\cdot[olefin]\cdot + olefin \longrightarrow R\cdot CFX\cdot[olefin]_2\cdot, \text{ etc.}$$

which is always competing with the chain transfer step

$$R\cdot CFX\cdot[olefin]\cdot + R\cdot CFXY \longrightarrow R\cdot CFX\cdot[olefin]\cdot Y + R\cdot CFX\cdot$$

depends upon (i) the ease of polymerisation of the olefin, (ii) the reactivity of the intermediate free radical R·CFX·[olefin]· towards olefin and towards R·CFXY, (iii) the stability of the product R·CFX·$[olefin]_n$·Y, and (iv) the relative ease of the chain-transfer step.

(i) An olefin which reacts readily with fragments from a decomposing peroxide to give a polymer of high molecular weight will, in general, tend to give a longer-chain polymer with R·CFXY than one which does not. This is illustrated by comparison of tetrafluoroethylene, chlorotrifluoroethylene, or trifluoroethylene with, say, ethylene or trichloroethylene. The ease of polymerisation is related to the ease of radical attack as discussed under (*a*).

(ii) This is clearly closely related to (*a*) and to (i), since the reactivity of the radical

R·CFX·[olefin]· produced by attack of R·CFX· on the olefin will determine the ease of attack on a second molecule of the olefin.

Why a radical such as R·CFX·CH_2·CH_2· should attack R·CFXY rather than another molecule of ethylene, whereas a radical such as R·CFX·CF_2·CF_2· should attack another molecule of tetrafluoroethylene rather than R·CFXY is clearly related to the difference between the C–Y and C–C bond energies in R·CFX·CH_2·CH_2Y and R·CFX·CH_2·CH_2–CH_2·CH_2· or in R·CFX·CF_2·CF_2Y and R·CFX·CF_2·CF_2–CF_2·CF_2·. Full discussion of this important factor is deferred, but the conclusions reached empirically by experiment are summarised in (*c*).

In special circumstances the choice of R·CFXY must be governed by the particular olefin to be polymerised. Thus, if trifluoroiodomethane is used as source of the R·CFX· radical (*i.e.*, CF_3) to attack chlorotrifluoroethylene, R·CFX is reactive, whereas the intermediate radical produced during polymerisation is CF_3·[CF_2·CFCl]$_n$·CF_2·CFCl·, which is less reactive. In the special situation where there are comparable concentrations of CF_3· and CF_3·[CF_2·CFCl]$_n$·CF_2·CFCl· radicals, therefore, the chlorotrifluoroethylene present will be attacked by the CF_3· radicals rather than by the CF_3·[CF_2·CFCl]$_n$·CF_2·CFCl· radicals. New reaction chains will thus predominate over propagation, and shorter-chain rather than longer-chain polymer will be produced. Such situations are rare, but the possibility should be considered when deciding upon reactant ratios and reaction conditions.

A case can also arise of the type discussed earlier in this paper where the initiating radical (*e.g.*, CF_2Cl·CFCl·) is of the same type as the intermediate radical (*e.g.*, CF_2Cl·CFCl·[CF_2·CFCl]$_n$·CF_2·CFCl·). Both initiating radical and intermediate radical can attack the olefin with equal facility (provided n is small), and if the formation of long-chain polymer is to be avoided, the chain transfer reaction must be made as efficient as possible, *e.g.*, by making Y = I rather than Br, and by increase in the ratio of transfer agent to olefin.

(iii) The stability of the product R·CFX·[olefin]$_n$·Y under the conditions used is important, since if the C–Y bond is weak, subsequent homolytic fission may occur to give the radical R·CFX·[olefin]$_n$· which can then initiate a new reaction chain. This leads to longer-chain polymer and to a wider spread in the value of n than is usually desirable. Choice of reaction conditions is important here. Thus if heat is used to cause C–Y fission in R·CFXY, and C–Y in R·CFX·[olefin]$_n$·Y is of approximately the same strength as C–Y in R·CFXY (*e.g.*, in the reaction of CF_2Cl·CFClI with CF_2:CFCl), then the further reaction of R·CFX·[olefin]$_n$·Y with olefin can be avoided only by use of a high ratio of R·CFXY to olefin. Use of ultraviolet light at room temperature is preferable in such a case to obtain maximum yields of short-chain polymer, since the concentration of R·CFX·[olefin]$_n$·Y in the chain-transfer agent R·CFXY is usually such that ultraviolet light entering the reaction vessel preferentially photolyses R·CFXY; the essential difference from use of heat is that only a relatively low percentage of the reaction mixture receives energy at any one instant. Heat is thus best used for those reactions where C–Y in the polymer is relatively strong (*e.g.*, in the reaction of CF_3I with C_2H_4).

(iv) The chain-transfer step can clearly be favoured by use of a high ratio of R·CFXY to olefin, and this often outweighs the factors (i)—(iii). Choice of reaction conditions affects this ratio, particularly when the olefin is gaseous. In this case only the liquid phase should be irradiated in a photochemical reaction, since here the ratio is high, as required, whereas in the gas phase the ratio is usually low (see *J.*, 1953, 3761, for illustrations of this). If heat is used instead of light, the olefin in the gas phase in the vessel used should be reduced to a minimum by use of sufficient transfer agent almost to fill the vessel, by use of sufficient pressure of olefin to cause it to liquefy and dissolve in the chain-transfer agent, or by use of an inert gas to achieve the same effect (cf. *J.*, 1953, 3761). Other aspects of the transfer step are discussed under (*c*).

(*c*) *Chain transfer.* (i) In the type of polymerisation under discussion, R·CFXY acts both as source of the initiating radical and as chain-transfer agent. The C–Y bond strength in R·CFXY is important in both these processes. If the C–Y bond is weak compared with that in the polymer (*e.g.*, the C–I bond in the reaction of trifluoroiodomethane with ethylene to give CF_3·[CH_2·CH_2]$_n$·I), then chain transfer will occur readily and n will be mainly 1

or 2, and often exclusively 1. If, on the other hand, the C–Y bond in R·CFXY is strong, *e.g.*, when Y = Cl, then chain transfer is difficult and the propagation reaction will be favoured; coupling of radicals to give R·CFX·[olefin]$_n$·[olefin]$_n$·CFX·R can become an import side-reaction in such circumstances. Formation of shorter-chain polymer can be favoured, but not necessarily achieved, by use of a high ratio of transfer agent to olefin.

(ii) If the chain transfer agent is efficient (*i.e.*, C–Y in R·CFXY is weak, yet R·CFX is sufficiently reactive to attack the olefin, *e.g.*, when R·CFXY = CF_3I, $CF_2Cl·CFClI$, or $CF_2Br·CFClBr$), a reactive olefin (*i.e.*, one which is readily polymerised by a peroxide) can be made to give polymer where n is low by control of the ratio transfer agent : olefin. Such olefins (*e.g.*, C_2F_4 and C_2F_3Cl) will not give exclusively the compound where $n = 1$, however, unless a very high (>10 : 1) ratio is used, and usually n will show a spread, *e.g.*, $n = 1$ (60%), 2 (20%), 3 (8%), 4 (3%), etc.

(iii) If the chain-transfer agent is efficient in the sense defined above, and the olefin is not reactive (*i.e.*, is not readily polymerised by a peroxide), then the product is R·CFX·[olefin]$_n$·Y where $n = 1$, and it becomes difficult to make $n \geqslant 1$. The C–Y bond in the polymer is not necessarily strong. Examples of such olefins taken from earlier work from these laboratories are C_2H_4, C_2H_2, $CH_2{:}CH·CF_3$, $CH_2{:}C{:}CH_2$, $CH_3·CH{:}CH_2$, $CF_3·CF{:}CF_2$, and CFCl:CFCl. Olefins which are of intermediate reactivity in this sense are $CH_2{:}CF_2$, $CH_2{:}CHF$, $CH_2{:}CHCl$, and $CH_2{:}CH·CO_2Me$. Attempts to force olefins such as ethylene, propene, 3 : 3 : 3-trifluoropropene, or hexafluoropropene to give a polymer R·CFX·[olefin]$_n$·Y with $n > 4$ or 5, by cutting down the proportion of chain-transfer agent R·CFXY, merely causes the intermediate radical (*e.g.*, $R·CFX·CH_2·\dot{C}H·CF_3$ from 3 : 3 : 3-trifluoropropene) to undergo mainly reactions other than by addition with a second molecule of olefin, *e.g.*, disproportionation, dimerisation, or internal expulsion of halogen to give an olefin.

Consideration of the various factors discussed above for a particular olefin under study makes it possible to achieve maximum yields of short-, medium-, or long-chain polymer with the minimum of experiments.

Experimental

1 : 2-Dichloro-1 : 2 : 2-trifluoroiodoethane was prepared from iodine monochloride and chlorotrifluoroethylene and purified by distillation (Part I, *loc. cit.*). Reactions were carried out in silica or Pyrex tubes unless otherwise stated, with precautions to exclude air and moisture. Distillations were carried out in nitrogen; this is particularly important for the iodo-compounds which are readily oxidised and are liable to form peroxides.

Reaction of 1 : 2-*Dichloro*-1 : 2 : 2-*trifluoroiodoethane with Chlorotrifluoroethylene.*—(a) *With a molar ratio* 15 : 1. In a typical experiment the iodo-compound (420 g., 1·5 mole) was shaken in a silica tube with chlorotrifluoroethylene (11·7 g., 0·1 mole) and the liquid phase was exposed to ultraviolet light (5 days). No chlorotrifluoroethylene remained, and distillation of the liquid products gave 1 : 2-dichloro-1 : 2 : 2-trifluoroiodoethane, b. p. 98—100°, 1 : 2 : 4-*trichlorohexafluoro*-4-*iodobutane* (75% based on olefin), b. p. 80°/25 mm. (Found: C, 12·1; Cl + I, 59·3. $C_4Cl_3IF_6$ requires C, 12·1; Cl + I, 59·1%), and a still residue (20% based on olefin) consisting of longer-chain material.

(b) *With equimolar ratio.* The last experiment was repeated with 0·25 mole of each reactant. The course of the reaction is easily followed by the increase in viscosity, and requires 2—7 days for completion. The shorter time applies to reaction in absence of solvent, the longer time applies when an inert solvent (1 : 1 : 2-trichlorotrifluoroethane) is used to prevent oily polymer from sticking to the sides of the tube and being decomposed by photolysis. No chlorotrifluoroethylene was recovered in either set of conditions, and distillation gave (*a*) unchanged 1 : 2-dichloro-1 : 2 : 2-trifluoroiodoethane, (*b*) 1 : 2 : 4-trichlorohexafluoro-4-iodobutane (18% based on olefin), b. p. 78—80°/20 mm., (*c*) 1 : 2 : 4 : 6-*tetrachlorononafluoro*-6-*iodohexane* (14% based on olefin), b. p. 140—142°/30 mm. (Found: C, 14·1; Cl + I, 52·5. $C_6Cl_4IF_9$ requires C, 14·1; Cl + I, 52·2%), (*d*) 1 : 2 : 4 : 6 : 8-*pentachlorododecafluoro*-8-*iodo-octane* (17% based on olefin), b. p. 135—140°/*ca.* 0·1 mm., n_D^{20} 1·435 (Found: C, 15·5; Cl + I, 48·5. $C_8Cl_5IF_{12}$ requires C, 15·3; Cl + I, 48·3%), and (*e*) a still residue (39% based on olefin) consisting mainly of Cl·[CF_2·CFCl]$_n$·I with $n = 5$ and 6.

The still residues from several such experiments were combined and distilled to give 1 : 2 : 4 : 6 : 8 : 10-*hexachloropentadecafluoro*-10-*iododecane*, b. p. 185—190°/*ca.* 0·1 mm., n_D^{20} 1·432 (Found: C, 16·3; Cl + I, 45·3. $C_{10}Cl_6IF_{15}$ requires C, 16·1; Cl + I, 45·6%), and

1 : 2 : 4 : 6 : 8 : 10 : 12-*heptachloro-octadecafluoro*-12-*iodododecane*, b. p. 200—208°/*ca.* 0·01 mm., n_D^{20} 1·428 (Found : C, 16·8; Cl + I, 43·0. $C_{12}Cl_7IF_{18}$ requires C, 16·8; Cl + I, 43·6%).

(c) *With an excess of chlorotrifluoroethylene.* In a typical experiment 1 : 2-dichloro-1 : 2 : 2-trifluoroiodoethane (0·05 mole) and chlorotrifluoroethylene (0·25 mole) were shaken and irradiated in a sealed silica tube with the vapour phase shielded from light (3 days). Distillation of the combined products from four such experiments gave the compounds Cl·[CF_2·CFCl]$_n$·I with n = 1 (0%), n = 2 (5%), n = 3 (7%), n = 4 (11%), n = 5 (13%), and n = 6 (12%). The b. p.s are as reported above, and yields based on CF_2Cl·CFClI are shown in parentheses. Further distillation gave 1 : 2 : 4 : 6 : 8 : 10 : 12 : 14-*octachloroheneicosafluoro*-14-*iodotetradecane* (12%), b. p. 230—240°/*ca.* 0·001 mm. (Found : C, 17·2; Cl + I, 41·9. $C_{14}Cl_8IF_{21}$ requires C, 17·2; Cl + I, 42·0%). At this point the high temperature caused liberation of iodine, particularly if traces of oxygen were present. The still residue was therefore transferred to a " molecular-distillation " unit and arbitrary fractions were taken. Control of bath-temperature was used to effect separation, and each fraction took approx. 4 hr. to distil. A series of fractions of the average composition shown in Table 2 were thus obtained.

TABLE 2.

n in Cl·[CF_2·CFCl]$_n$·I	8	9	10	11
Yield (%)	7	4	5	4
C (found); Calc. in parentheses (%)	17·5(17·5)	17·7(17·8)	18·0(18·1)	18·4(18·3)

The colourless residue (16% based on CF_2Cl·CFClI) became pink on exposure to ultraviolet light, and a qualitative test for iodine was strongly positive. When cold the residue was a hard wax but it was quite mobile when hot. It had the average composition Cl·[CF_2·CFCl]$_{20}$·I (Found : C, 19·4; Cl + I, 34·0. Calc. for $C_{40}Cl_{21}IF_{80}$: C, 19·2; Cl + I, 35·0%). Attempts to separate it further by molecular distillation gave solids which could not be purified by recrystallisation to give analytically pure compounds. The solids were mixtures of homologues, and resembled poly(tetrafluoroethylene) in appearance and feel.

Each of the above compounds was redistilled to obtain clean separation from its homologues before analysis. The compounds are thermally stable and decompose rapidly at room temperature only if kept in presence of air or moisture, particularly when exposed to light.

Reaction of the Compounds Cl·[CF_2·CFCl]$_n$·I *with Chlorine.*—(a) 1 : 2 : 4-*Trichlorohexafluoro*-4-*iodobutane*. This compound (12·6 g.) and chlorine (20% excess) were exposed to ultraviolet light in a silica tube (2 days). The products were shaken with 10% aqueous sodium hydroxide to remove iodine trichloride, dried (P_4O_{10}), and distilled to give 1 : 1 : 3 : 4-*tetrachlorohexafluorobutane* (96%), b. p. 133—134° (Found : C, 15·5; Cl, 46·6. $C_4Cl_4F_6$ requires C, 15·8; Cl, 46·7%).

(b) *Polymer* Cl·[CF_2·CFCl]$_n$·I. The crude iodine-containing polymer (40·7 g.), obtained by use of an excess of chlorotrifluoroethylene as described above, was sealed in a silica tube with 1 : 1 : 2-trichlorotrifluoroethane (50 ml.) as inert diluent, and dry chlorine (10% excess). The tube was shaken vigorously and exposed to ultraviolet light (7 days). The deposited iodine trichloride was removed by treatment with aqueous sodium hydroxide, and the dried organic layer was distilled to give diluent and the *compounds* shown in Table 3.

TABLE 3. *Compounds* Cl·[CF_2·CFCl]$_n$·Cl.

				Found		Reqd.	
n	B. p./mm.	n_D	Yield (%)	C	Cl	C	Cl
2	78°/100	—	7	15·5	46·6	15·8	46·7
3	96—98/20 (*ca.* 205/760)	1·397 *	7	17·0	42·4	17·1	42·2
4	145—147/20	1·408 †	9	17·8	39·8	17·9	39·7
5	135—139/*ca.* 0·1	1·413 †	8	18·5	37·5	18·4	38·0
6	190—195/*ca.* 0·1	—	12	18·7	36·3	18·7	36·9
7	235—240/0·1—0·01	—	14	19·0	36·1	19·0	36·7

* At 20°. † At 22°.

The still residue was transferred to a " molecular " still where slow distillation gave Cl·[CF_2·CFCl]$_7$·Cl (*ca.* 1%), then a fraction (probably 1 : 1 : 3 : 5 : 7 : 9 : 11 : 13 : 15 : 16-*decachlorotetracosafluorohexadecane*) of average composition Cl·[CF_2·CFCl]$_8$·Cl (10%) (Found : C, 19·1. $C_{16}Cl_{10}F_{34}$ requires C, 19·2%). The residue had average composition Cl·[CF_2·CFCl]$_{18}$·Cl [Found : C, 20·0. Calc. for $C_{36}Cl_{20}F_{74}$: C, 20·0, cf. (CF_2·CFCl)$_8$: C, 20·6%].

1 : 2 : 4-*Trichloroheptafluorobutane*.—To 1 : 2 : 4-trichlorohexafluoro-4-iodobutane (2·7 g.)

and carbon tetrachloride (5 ml.) in a silica flask was added a solution of chlorine trifluoride (*ca.* 2 g.) in carbon tetrachloride (5 ml.), at such a rate that the vigorous reaction did not get out of control (1 hr.). After being kept (3 hr.), water (5 ml.) was added followed by an excess of 5% aqueous sodium hydroxide. Distillation of the dried (P_4O_{10}) organic liquid gave 1 : 2 : 4-*trichloroheptafluorobutane* (84%), b. p. 99—100° (Found: C, 16·8%; *M*, 286. $C_4Cl_3F_7$ requires C, 16·7%; *M*, 287·5).

Synthesis and Reactions of 4 : 4-*Dichlorohexafluorobut*-1-*ene and* 3 : 3-*Dichlorotrifluoropropionic Acid.*—(a) 1 : 1 : 3 : 4-Tetrachlorohexafluorobutane (8·3 g.) was dissolved in ethanol (20 ml.) and added dropwise at 60° to a stirred suspension of zinc dust (25 g.) in ethanol (30 ml.). After 1 hr. the volatile components were slowly distilled off and collected in a flask containing water; ethanol was added to the reaction flask during this process at a rate sufficient to keep the volume in it constant. The liquid obtained as the lower layer in the receiver was washed with water, dried, and distilled to give 4 : 4-*dichlorohexafluorobut*-1-*ene* (78%), b. p. 70—71° (Found: C, 20·7; Cl, 30·2%; *M*, 232. $C_4Cl_2F_6$ requires C, 20·6; Cl, 30·5%; *M*, 233).

The absence of 1 : 2 : 3 : 4-tetrachlorohexafluorobutane in the 1 : 1 : 3 : 4-isomer was shown by the fact that vigorous refluxing of the last compound (5·7 g.) or of 4 : 4-dichlorohexafluorobut-1-ene (4·8 g.) with zinc and ethanol failed to give hexafluorobutadiene (cf. Part I, *loc. cit.*). Under these more vigorous conditions compounds containing hydrogen, probably $CF_2{:}CF{\cdot}CF_2{\cdot}CHFCl$, $CF_2{:}CF{\cdot}CF_2{\cdot}CH_2F$, etc., are formed by reduction of the $CFCl_2$ group.

Reaction of 4 : 4-dichlorohexafluorobut-1-ene (2·6 g.) with a slight excess of chlorine was rapid on exposure to ultraviolet light (8 hr.) and gave an almost quantitative yield of the parent 1 : 1 : 3 : 4-tetrachlorohexafluorobutane. The olefin (1·7 g.) similarly reacted with an excess of bromine (4 hr.) to give 1 : 2-*dibromo*-4 : 4-*dichlorohexafluorobutane* (91%), b. p. 65°/5 mm. n_D^{20} 1·427 (Found: C, 12·4; Br + Cl, 58·4. $C_4Br_2Cl_2F_6$ requires C, 12·2; Br + Cl, 58·8%). The dibromo-compound reverted to the olefin when treated with zinc and ethanol at 40° (1 hr.).

(b) 4 : 4-Dichlorohexafluorobut-1-ene (10·2 g.) was oxidised with aqueous potassium permanganate by the method developed for the oxidation of compounds which contain the $CF{:}CF_2$ group (*J.*, 1952, 4259) as modified for the oxidation of compounds which also contain chlorine (Part III, *loc. cit.*). Control of pH was essential to prevent extensive breakdown, and this was achieved either by intermittent addition of aqueous sodium hydroxide as before, or by use of sodium hydrogen carbonate as a buffer. The reaction mixture was worked up in the usual manner (sulphur dioxide, sulphuric acid, ether-extraction), and the dried ($MgSO_4$) ethereal extracts were distilled from 0·1 g. of phosphoric oxide to give ββ-*dichlorotrifluoropropionic acid* (62%), b. p. 83—85°/20 mm. (Found: C, 18·2; H, 0·8%; equiv., 196·7. $C_3HO_2Cl_2F_3$ requires C, 18·3; H, 0·5%; equiv., 197·0).

Reaction of the acid with silver carbonate followed by freeze-drying gave the silver salt which was thoroughly dried over phosphoric oxide *in vacuo*. The silver salt (3·2 g.) was pyrolysed at 10 mm. in a platinum tube heated rapidly from 150° to 400°. The volatile products, collected in a trap cooled by liquid oxygen, contained carbon dioxide and unidentified material of b. p. <100°, but 1 : 1 : 4 : 4-tetrachlorohexafluorobutane was not detected. The residue in the pyrolysis tube contained silver, silver chloride, and carbon.

A second sample of the silver salt (2·6 g.) was sealed with an excess of dry chlorine and heated stepwise to 120° (2 hr.). Fractionation gave 1 : 1 : 2-trichlorotrifluoroethane (78%), b. p. 47°, identified spectroscopically.

Sodium ββ-dichlorotrifluoropropionate was prepared by neutralisation of the acid followed by freeze-drying. The dried (P_4O_{10}) salt (3·8 g.) was placed in a platinum tube closed at one end and connected *via* a trap cooled in liquid oxygen to a pump. The pressure in the platinum tube was maintained at <1 mm., and the tube was slowly pushed into a furnace heated to 320°, and finally to 420°. Sodium chloride with only a trace of sodium fluoride remained as residue. The volatile products which had collected in the trap were carbon dioxide and chlorotrifluoroethylene (83%), identified spectroscopically.

Synthesis and Reactions of 4 : 6 : 6-*Trichlorononafluorohex*-1-*ene and* 3 : 5 : 5-*Trichlorohexafluoropentanoic Acid.*—1 : 1 : 3 : 5 : 6-Pentachlorononafluorohexane (15·7 g.) was dissolved in ethanol (35 ml.) and added dropwise to zinc (30 g.) and ethanol (30 ml.), stirred vigorously, and heated to 50°. After 1 hr. the mixture was filtered and added to an excess of water. The organic layer was dried and distilled, to give 4 : 6 : 6-*trichlorononafluorohex*-1-*ene* (59%), b. p. 80—82°/105 mm. (Found: C, 20·7; Cl, 30·1. $C_6Cl_3F_9$ requires C, 20·6; Cl, 30·5%), and unidentified more volatile products which contained hydrogen and were formed in increased yield if a higher temperature was used for the dechlorination. This dechlorination is very

sensitive to conditions. Reaction of the olefin with zinc and refluxing ethanol did not give a diene, but only a mixture of mono-olefins containing hydrogen which could not be resolved into pure compounds.

4 : 6 : 6-Trichlorononafluorohex-1-ene (7·7 g.) was oxidised by potassium permanganate (4·2 g.), water (35 ml.), and sodium hydrogen carbonate (5 g.) at 70° (8 hr.) and the acid produced was extracted by ether in the usual way. Distillation of the dried ethereal extracts from 0·1 g. of phosphoric oxide gave **3 : 5 : 5-*trichlorohexafluoropentanoic acid*** (57%), b. p. 135°/18 mm. (Found: C, 19·2; H, 0·3; Cl, 33·7%; equiv., 313. $C_5HO_2Cl_3F_6$ requires C, 19·1; H, 0·3; Cl, 34·0%; equiv., 313·5).

The sodium salt (2·3 g.) was prepared by neutralisation of the acid, isolated by freeze-drying, and dried *in vacuo*. It was then pyrolysed as described for sodium ββ-dichlorotrifluoropropionate at 320—400°/1—5 mm. The products which condensed in the trap cooled by liquid oxygen were **4 : 4-dichlorohexafluorobut-1-ene** (63%), b. p. 70—71° (Found: C, 20·6. Calc. for $C_4Cl_2F_6$: C, 20·7%), identical with the olefin described earlier.

The silver salt (2·8 g.) was thoroughly dried *in vacuo*, then heated with chlorine (15% excess) at 130° (3 hr.). The products were removed by pumping through a cooled trap, and the excess of chlorine and the carbon dioxide allowed to escape. The residual liquid was washed with aqueous sodium hydroxide, then distilled to give an initial fraction (0·15 g.), b. p. 79—82°, followed by **1 : 1 : 3 : 4-tetrachlorohexafluorobutane** (55%), b. p. 132—134° (Found: C, 15·8. $C_4Cl_4F_6$ requires C, 15·8%), identical with the compound described earlier.

Polyfluoroalkanesulphonic Acids.—(a) *From* **4 : 4-*dichlorohexafluorobut*-1-*ene***. The olefin (4·6 g., 0·020 mole) was shaken with sodium sulphite (2·5 g., 0·021 mole), borax (2 g.), water (12 ml.), and benzoyl peroxide (0·5 g.) and heated at 80° (2 hr.), 100° (1 hr.) and 110° (8 hr.). No olefin was recovered. The filtered aqueous solution was freeze-dried to give a white solid. An attempt to generate the free sulphonic acid by heating half of the solid with concentrated sulphuric acid was unsuccessful, since hydrogen fluoride was liberated and caused extensive etching. The second half of the solid was therefore extracted with boiling absolute alcohol (3 times), and evaporation of the ethanol *in vacuo* gave the pure sodium salt of the sulphonic acid. This was dried over phosphoric oxide, then heated *in vacuo* with fuming sulphuric acid to give **4 : 4-*dichloro*-1 : 1 : 2 : 3 : 3 : 4-*hexafluorobutanesulphonic acid*** (69% total yield), which when redistilled had b. p. 118—120°/3·5 mm. (Found: C, 15·0; H, 0·4; Cl, 21·7%; equiv., 317. $C_4H_2O_3Cl_2F_6S$ requires C, 15·2; H, 0·6; Cl, 22·5%; equiv., 315).

(b) **4 : 6 : 6 *Trichlorononafluorohex*-1-*ene***. This olefin (0·022 mole) was treated with a similar mixture to that in (a) for the same time. The product was isolated by freeze-drying and extraction with ethanol, then distilled from sulphuric acid to give **4 : 6 : 6-*trichloro*-1 : 1 : 2 : 3 : 3 : 4 : 5 : 5 : 6-*nonafluorohexanesulphonic acid*** (57%), and when redistilled had b. p. 130—133°/*ca.* 0·1 mm. (Found: C, 16·5; H, 0·5; Cl, 24·4%; equiv., 428. $C_6H_2O_3Cl_3F_9S$ requires C, 16·7; H, 0·5; Cl, 24·8%; equiv., 431·5).

Photochemical Oxidation of Compounds $Cl{\cdot}[CF_2{\cdot}CFCl]_n{\cdot}I$.—(*a*) The compound $Cl{\cdot}[CF_2{\cdot}CFCl]_2{\cdot}I$ (4·3 g.) was sealed in a 200 ml. silica tube with oxygen (7 atm.) and 10% aqueous sodium hydroxide (20 ml.) and shaken vigorously in a horizontal position so that the organic liquid was distributed over the sides of the tube. After exposure to an ultraviolet lamp 5 cm. from the tube for 12 hr., the tube was opened and recharged with oxygen. After further irradiation (12 hr.) the excess of oxygen was pumped away. There was no residual organic layer after acidification with hydrochloric acid and allowing the emulsion to separate. The aqueous solution was extracted with ether (10 × 20 ml.) and distillation of the dried ethereal extracts gave **3 : 4-*dichloropentafluorobutanoic acid*** (63%), b. p. 105—107°/25 mm. (Found: C, 19·5%; equiv., 250. $C_4HO_2Cl_2F_5$ requires C, 19·4%; equiv., 247).

(*b*) The compound $Cl{\cdot}[CF_2{\cdot}CFCl]_5{\cdot}I$ (5·7 g.) was sealed in a silica tube with oxygen (8 atm.) and 1 : 2-dichlorotetrafluoroethane (20 ml.) as diluent, shaken vigorously, and exposed to ultraviolet light (8 hr.). Distillation of the product gave unchanged iodo-compound (2·1 g.) and a more volatile fraction which showed acyl fluoride absorption in the infrared (5·3 μ). When the last fraction was treated with aqueous sodium hydroxide, fluoride but not chloride was liberated. Acidification (hydrochloric acid) gave an organic layer which solidified when separated; infrared spectroscopic examination showed it to contain a CO_2H group. The aqueous solution was extracted with ether, evaporation of which left a colourless oil which spectroscopic examination showed also contained a CO_2H group. The combined yield of the acid $Cl{\cdot}[CF_2{\cdot}CFCl]_4{\cdot}CF_2{\cdot}CO_2H$ was 57%. Its equivalent was determined by titration of its solution in aqueous dioxan with aqueous sodium hydroxide (Found: equiv., 605. $C_{10}HO_2Cl_5F_{14}$ requires equiv., 596·5).

(*c*) A mixture (5 g.) of compounds $Cl\cdot[CF_2\cdot CFCl]_n\cdot I$ where n had an average value of 6 was heated stepwise to 150° during 5 hr. in a sealed shaken tube containing water (20 ml.), benzoyl peroxide (0·1 g.), ammonium persulphate (0·1 g.), and oxygen (3 atm.). A further amount of oxygen and benzoyl peroxide was added, and the tube heated as before. The acidic aqueous solution was made alkaline with aqueous sodium hydroxide, filtered to remove decomposition products arising from the benzoyl peroxide, acidified (hydrochloric acid), then extracted with ether. Distillation of the dried ethereal extracts gave a mixture of polyfluoro-carboxylic acids (42%), b. p. 65—130°/0·01 mm., and a residue (26%) of a clear wax which was free from iodine and carboxyl groups. The mixed polyfluoro-acids had equiv. 680, revealing an average composition $Cl\cdot[CF_2\cdot CFCl]_5\cdot CF_2\cdot CO_2H$ (equiv., 713).

(*d*) The compound $Cl\cdot[CF_2\cdot CFCl]_2\cdot I$ (6·1 g.), oxygen (5 atm.), and water (10 ml.) were shaken vigorously and exposed to ultraviolet light (2 days). The tube was recharged with oxygen and again irradiated (2 days). The acidic solution was extracted with ether (10 + 15 ml.) and the dried ethereal extracts were distilled, to give 3 : 4-dichloropentafluorobutanoic acid (57%), b. p. 98—100°/23 mm.

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Fluoro-olefins. Part V. Fluoro-dienes and -trienes and Perfluoromalonic Acid.*

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The compounds $Cl\cdot[CF_2\cdot CFCl]_n\cdot I$ can be coupled to give $Cl\cdot[CF_2\cdot CFCl]_n\cdot[CFCl\cdot CF_2]_n\cdot Cl$.
Dienes, trienes (*e.g.*, $CF_2{:}CF\cdot CF_2\cdot CF{:}CF\cdot CF_2\cdot CF{:}CF_2$), and polyfluoro-acids [*e.g.*, $CF_2(CO_2H)_2$ and $(CFCl\cdot CF_2\cdot CO_2H)_2$] have been synthesised from the coupled products, and reactions of the salts of the acids are described.

THE coupling of polyfluoroalkyl chains was originally demonstrated with heptafluoroiodopropane, 1-chlorohexafluoro-1-iodopropane and 1 : 2-dichlorotrifluoro-1-iodoethane :

$$C_3F_7I \longrightarrow C_6F_{14};\quad C_3F_6\cdot CFClI \longrightarrow (C_3F_6\cdot CFCl)_2;\quad CF_2Cl\cdot CFClI \longrightarrow (CF_2Cl\cdot CFCl)_2$$

and is achieved by use of mercury and ultraviolet light or by zinc in an inert solvent, preferably free from active hydrogen, such as dioxan (Haszeldine, *J.*, **1952**, 4423; Haszeldine and Steele, *J.*, **1953**, 1592; Haszeldine and Walaschewski, *J.*, **1953**, 3607). Henne, and Henne and Postelneck (*J. Amer. Chem. Soc.*, **1953**, **75**, 5750; **1955**, **77**, 2334), have confirmed the reaction with 1 : 2-dichlorotrifluoro-1-iodoethane and heptafluoroiodopropane.

The synthesis of compounds of general formula $Cl\cdot[CF_2\cdot CFCl]_n\cdot I$ by interaction of 1 : 2-dichlorotrifluoro-1-iodoethane and chlorotrifluoroethylene was described in Part IV (*loc. cit.*). These compounds contain a terminal –CFClI group and can thus be coupled readily either by use of mercury and ultraviolet light, or by use of zinc in an inert solvent as outlined above :

$$Cl\cdot[CF_2\cdot CFCl]_n\cdot I \xrightarrow{Hg,h\nu} Cl\cdot[CF_2\cdot CFCl]_n\cdot \longrightarrow Cl\cdot[CF_2\cdot CFCl]_n\cdot[CFCl\cdot CF_2]_n\cdot Cl \quad (I)$$

Such coupled compounds (I) contain a poly(chlorotrifluoroethylene) chain of a new type. They are isomers of the compounds $Cl\cdot[CF_2\cdot CFCl]_m\cdot Cl$ described in Part IV, but are capable of more extensive use in synthesis, since they contain a central –CFCl·CFCl– group which

$$CF_2{:}CF\cdot[CF_2\cdot CFCl]_n\cdot[CFCl\cdot CF_2]_m\cdot CF{:}CF_2 \quad (A)$$

$$CF_2{:}CF\cdot[CF_2\cdot CFCl]_m\cdot CF_2\cdot CF{:}CF\cdot CF_2\cdot[CFCl\cdot CF_2]_n\cdot CF{:}CF_2 \quad (B)$$

can be converted into –CF:CF–, as well as the terminal $CF_2Cl\cdot CFCl$– groups which give $CF_2{:}CF$– groups. Dechlorination of $CF_2Cl\cdot CFCl$– is easier than dechlorination of

* Part IV, preceding paper.

–CFCl·CFCl– so terminal diolefins (A) or triolefins (B) can be obtained by control of conditions. This is illustrated by the synthesis of perfluoro-octa-1 : 4 : 7-triene (II) :

$$Cl\cdot[CF_2\cdot CFCl]_3\cdot I \xrightarrow{Hg,h\nu} Cl\cdot[CF_2\cdot CFCl]_3\cdot[CFCl\cdot CF_2]_3\cdot Cl \xrightarrow[50°]{Zn\text{–}EtOH} (CF_2{:}CF\cdot CF_2\cdot CFCl)_3$$

$$\downarrow Zn\text{–}EtOH\ 75° \qquad Zn\text{–}EtOH\ 75° \swarrow$$

$$CF_2{:}CF\cdot CF_2\cdot CF{:}CF\cdot CF_2\cdot CF{:}CF_2 \quad (II)$$

The di- and tri-olefins (III) and (IV) are similarly formed from $Cl\cdot[CF_2\cdot CFCl]_3\cdot I$:

$(CF_2{:}CF\cdot CF_2\cdot CFCl\cdot CF_2\cdot CFCl)_2$ (III) $\qquad$ $CF_2{:}CF\cdot CF_2\cdot CFCl\cdot CF_2\cdot CF{:}CF\cdot CF_2\cdot CFCl\cdot CF_2\cdot CF{:}CF_2$ (IV)

These are the first polyfluorotrienes to be described. The double bonds are not conjugated so that the trienes behave as a terminal olefin such as $C_2F_5\cdot CF{:}CF_2$ and a symmetrical olefin such as $CF_3\cdot CF{:}CF\cdot CF_3$; the terminal double bonds are attacked more rapidly by electrophilic reagents or free radicals than the central double bond (Haszeldine and Osborne, in the press).

The dienes and trienes are oxidised at controlled pH to give dicarboxylic acids. For example, perfluoromalonic acid is obtained in good yield, thus proving the structure of (II) :

$$CF_2{:}CF\cdot CF_2\cdot CF{:}CF\cdot CF_2\cdot CF{:}CF_2 \xrightarrow{Aq.\ KMnO_4} CF_2(CO_2H)_2$$

Henne and De Witt (*J. Amer. Chem. Soc.*, 1948, **70**, 1548) reported that perfluoromalonic acid was unstable and was readily decarboxylated to difluoroacetic acid. This has not been our experience, and isolation and purification of the acid offered no difficulties. Evans and Tatlow's experience (*J.*, 1954, 3779) with perfluoromalonic acid prepared by oxidation of perfluoro*cyclo*hexa-1 : 4-diene was similar to ours.

Permanganate oxidation of 4 : 5-dichlorododecafluoro-octa-1 : 7-diene affords 3 : 4-dichlorohexafluoroadipic acid (V), the anhydrous disilver salt of which with chlorine gives the known 1 : 2 : 3 : 4-tetrachlorohexafluorobutane, and this in turn yields hexafluorobutadiene :

$$(CF_2{:}CF\cdot CF_2\cdot CFCl)_2 \xrightarrow{KMnO_4} \underset{(V)}{(CFCl\cdot CF_2\cdot CO_2H)_2} \longrightarrow (CFCl\cdot CF_2\cdot CO_2Ag)_2$$

$$(CFCl\cdot CF_2\cdot CO_2Ag)_2 \xrightarrow{Cl_2} (CFCl\cdot CF_2Cl)_2 \xrightarrow{Zn\text{–}EtOH} CF_2{:}CF\cdot CF{:}CF_2$$

The application of the silver-salt degradation to polyfluoro-acids containing chlorine was demonstrated recently (Haszeldine and Osborne, Part III, *J.*, 1955, 3880; Haszeldine, Part IV). The above reactions prove the structure of (V), and hence of the parent diene and the original coupled product.

Pyrolysis of anhydrous disodium 3 : 4-dichlorohexafluoroadipate gives a high yield of hexafluorobutadiene by loss of chloride from a polyhalogenocarbanion (cf. *J.*, 1951, 5844, 1952, 993, 4259; 1954, 4026; Parts III and IV, *locc. cit.*). The loss of chloride rather than fluoride is noteworthy, since it leads to a higher yield of hexafluorobutadiene than that obtained by pyrolysis of disodium octafluoroadipate (*J.*, 1954, 4026) :

$$(CFCl\cdot CF_2\cdot CO_2Na)_2 \longrightarrow {}^-CF_2\cdot CFCl\cdot CFCl\cdot CF_2{}^- + 2CO_2 + 2Na^+$$

$$\bar{C}F_2\text{—}CF(Cl)\text{—}CF(Cl)\text{—}\bar{C}F_2 \longrightarrow CF_2{:}CF\cdot CF{:}CF_2 + 2Cl^-$$

Further reactions of the dienes and trienes are under investigation.

Experimental

Coupling of compounds which contain the $-CFClI$ group is most conveniently brought about in a silica tube by use of mercury and ultraviolet light. Vigorous shaking is essential with sufficient excess of mercury to keep the contents mobile. Addition of an inert diluent prevents the caking of mercury iodides on the walls of the tube which cuts out the light. Photochemical coupling gives a product uncontaminated by the olefinic or hydrogen-containing materials which are obtained as by-products when zinc is used to effect coupling. This only becomes important when compounds which contain more than 6—8 carbon atoms are coupled, and the shorter-chain compounds can conveniently be coupled by use of zinc–dioxan, etc.

Coupling of Compounds $Cl\cdot[CF_2\cdot CFCl]_n\cdot I$.—(*a*) The compound $Cl\cdot[CF_2\cdot CFCl]_2\cdot I$ (5·1 g.) was diluted with 1 : 1 : 2-trichlorotrifluoroethane (5 ml.) and shaken vigorously with mercury (20 ml.) in a silica tube exposed to ultraviolet light (8 days). Ether-extraction of the organic material followed by distillation gave 1 : 2 : 4 : 5 : 7 : 8-*hexachlorododecafluoro-octane* (81%), b. p. 142—144°/20 mm., n_D^{25} 1·408 (Found: C, 17·9; Cl, 39·7. $C_8Cl_6F_{12}$ requires C, 17·9; Cl, 39·7%).

(*b*) The compound $Cl\cdot[CF_2\cdot CFCl]_3\cdot I$ (4·9 g.), treated as in (*a*), gave 1 : 2 : 4 : 6 : 7 : 9 : 11 : 12-*octachloro-octadecafluorododecane* (74%), b. p. 195—200°/*ca.* 0·1 mm. (Found: C, 18·7; Cl, 36·8. $C_{12}Cl_8F_{16}$ requires C, 18·7; Cl, 36·9%).

Dechlorination of Compounds $Cl\cdot[CF_2\cdot CFCl]_n\cdot[CFCl\cdot CF_2]_n\cdot Cl$.—(*c*) The compound $Cl\cdot[CF_2\cdot CFCl]_2\cdot[CFCl\cdot CF_2]_2\cdot Cl$ (6·7 g.), prepared as described above, was diluted with ethanol (20 ml.) and added dropwise to zinc and refluxing ethanol. After 1 hr. the product was filtered and added to an excess of water. Distillation of the lower layer from phosphoric oxide gave *perfluoro-octa*-1 : 4 : 7-*triene* (78%), b. p. 99—100° (Found: C, 29·8; H, 0; F, 70·0%; *M*, 325. C_8F_{12} requires C, 29·6; H, 0; F, 70·4%; *M*, 324), and an unidentified fraction of higher b. p.

The triene was reconverted into the parent chloro-compound by photochemical reaction with a 100% excess of chlorine (6 hr.), thus proving that the triene was not contaminated by compounds containing hydrogen.

(*d*) When reaction (*c*) with zinc was repeated at 50—55° (10 hr.) only a small amount of triene was obtained, and the major product was 4 : 5-*dichlorododecafluoro-octa*-1 : 7-*diene* (51%), b. p. 58°/20 mm. (Found: C, 24·2; H, 0; Cl, 17·7. $C_8Cl_2F_{12}$ requires C, 24·3; H, 0; Cl, 18·0%). Unchanged material (30%) was also present.

(*e*) The compound $Cl\cdot[CF_2\cdot CFCl]_3\cdot[CFCl\cdot CF_2]_3\cdot Cl$ (8·0 g.) was treated as in (*c*), to give 4 : 9-*dichloro-octadecafluorododeca*-1 : 6 : 11-*triene*, b. p. 115—120°/20 mm. (Found: C, 25·6; H, 0; Cl, 12·6. $C_{12}Cl_2F_{18}$ requires C, 25·8; H, 0; Cl, 12·8%). This triene (2·0 g.) absorbed 3 mols. of chlorine when treated with an excess and exposed to ultraviolet light (24 hr.).

(*f*) Mild treatment of the compound $Cl\cdot[CF_2\cdot CFCl]_3\cdot[CFCl\cdot CF_2]_3\cdot Cl$ (7·3 g.) with zinc and ethanol as in (*d*) gave 4 : 6 : 7 : 9-*tetrachloro-octadecafluorododeca*-1 : 11-*diene* (56%), b. p. 150—152°/0·1 mm. (Found: C, 22·8; H, 0; Cl, 22·2. $C_{12}Cl_4F_{16}$ requires C, 22·9; H, 0; Cl, 22·6%).

Perfluoromalonic Acid.—Perfluoro-octa-1 : 4 : 7-triene (5·7 g.) was oxidised by aqueous potassium permanganate in presence of sodium hydrogen carbonate (Part III, *loc. cit.*) at 35° (1 hr.) then at 60° (1 hr.). The products were worked up as usual (*J.*, 1950, 2789; Part III) to give an ethereal solution of an acid. Evaporation of the ether left crude perfluoromalonic acid (63%) which, after distillation at 10^{-3} mm. or recrystallisation from benzene, had m. p. 118° (Found: C, 25·7%; equiv., 70. Calc. for $C_3H_2O_3F_2$: C, 25·7%; equiv., 70). This acid can be heated to 160° without decarboxylation. Evans and Tatlow report m. p. 117—118°.

Treatment of an ethereal solution of difluoromalonic acid prepared as above with diazomethane (cf. Henne and De Witt, *loc. cit.*), rather than isolation of the free acid, gave dimethyl perfluoromalonate (81%), b. p. 60—62°/12 mm. (Found: C, 35·6; H, 3·5. Calc. for $C_5H_6O_4F_2$: C, 35·7; H, 3·6%). The absence of methyl difluoroacetate suggests that the difluoroacetic acid obtained by Henne and De Witt was a primary product of their oxidation reaction. For final characterisation an ethereal solution of the dimethyl ester (0·1 g.) was treated with anhydrous ammonia to give perfluoromalonamide, m. p. 207° (Henne and De Witt report m. p. 206·4°) (Found: C, 26·0; H, 2·8; N, 20·3. Calc. for $C_3H_4O_2N_2F_2$: C, 26·1; H, 2·9; N, 20·3%). The infrared spectrum of the amide was identical with that of a specimen prepared by an alternative route.

3 : 4-*Dichlorohexafluoroadipic Acid.*—4 : 5-Dichlorododecafluoro-octa-1 : 7-diene (8·7 g.) was oxidised as described for the preparation of perfluoromalonic acid. Evaporation of the dried ethereal extracts gave 3 : 4-*dichlorohexafluoroadipic acid* as a wax (51%) which was sublimed at 10^{-3} mm., then analysed without further purification (Found: C, 22·6; H, 0·6; Cl, 22·2%;

equiv., 161·5. $C_6H_2O_4Cl_2F_6$ requires C, 22·3; H, 0·6; Cl, 22·0%; equiv., 162·5). A portion (0·8 g.) was redissolved in ether and treated with diazomethane, to give *dimethyl* 3 : 4-*dichlorohexafluoroadipate* (0·5 g.), b. p. 155—158°/2—4 mm. (Found: C, 27·4; H, 1·6; Cl, 20·0. $C_8H_4O_4Cl_2F_6$ requires C, 27·4; H, 1·7; Cl, 20·2%).

The rest of the acid was divided equally and converted into the silver and sodium salts which were thoroughly dried *in vacuo*. Reaction of the disilver salt (1·0 g.) with chlorine (10% excess) at 120° in a sealed tube gave 1 : 2 : 3 : 4-tetrachlorohexafluorobutane (69%), b. p. 130—133°; this was heated (80°) with zinc (1·0 g.) and ethanol (5 ml.) in a sealed tube (3 hr.) to give hexafluorobutadiene (67%), identical with a known sample (*J.*, 1952, 4423).

The *disodium salt* (2·1 g.) (Found: Na, 12·5. $C_6O_4Cl_2F_6Na_2$ requires Na, 12·7%) was pyrolysed *in vacuo* in a platinum tube at 150° rising to 420° (2 hr.). The gaseous product was washed with 5% aqueous sodium hydroxide to remove carbon dioxide, then distilled *in vacuo* to give hexafluorobutadiene (71%), identified by its infrared spectrum.

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Mixed Liquid Crystals. Part II. The Effect of Structure on the Transition Temperatures of Mixed Liquid Crystals.*

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Continuing an earlier investigation * we have studied additional binary systems in which one component can itself form liquid crystals. Conclusions are drawn concerning the relation between chemical structure and ability to form liquid crystals, and the shapes of the transition lines in the phase diagrams are discussed.

EARLIER * we described a study of several binary systems in which one component (*p*-azoxyanisole) can exist in a nematic liquid-crystalline form. We have now examined a number of additional systems with the object of obtaining information about the factors that control liquid-crystal formation. As in the systems studied previously, the birefringent two-component liquids obtained invariably behaved as single phases, and the transitions to and from normal liquid were sharp. The phase diagrams were of the types previously reported.

EXPERIMENTAL

Preparation and Purification of Materials.—p-*Bromo*-N-4-*methylbenzylideneaniline.* Equimolecular proportions of *p*-tolualdehyde and *p*-bromaniline were heated slowly in a little alcohol until the mixture boiled; the residue, on cooling, was crystallised several times from alcohol, forming colourless plates, m. p. 133° (Found: C, 61·5; H, 4·6; N, 5·2; Br, 28·9. $C_{14}H_{12}NBr$ requires C, 61·3; H, 4·4; N, 5·1; Br, 29·2%).

N-p-Anisylidene-*p*-dimethylaminoaniline (m. p. 146°), *N-p*-nitrobenzylidene-*p*-toluidine (m. p. 124°), *N*-4-nitrobenzylidene-*p*-anisidine (m. p. 136°), *p*-dimethylamino-*N*-4-nitrobenzylideneaniline (m. p. 220°), *N*-4-chlorobenzylidene-*p*-toluidine (m. p. 128°), *p*-chloro-*N*-4-chlorobenzylideneaniline (m. p. 112°), *p*-dimethylamino-*N*-4-methylbenzylideneaniline (m. p. 146°), *N*-4-methylbenzylidene-*p*-toluidine (m. p. 93·5°), *N*-4-methylbenzylideneaniline (m. p. 45°), *N*-benzylidene-*p*-anisidine (m. p. 71°), *N*-benzylidene-*p*-dimethylaminoaniline (m. p. 101°),

* Part I, *J.*, 1954, 4616.

and *N*-benzylideneaniline (m. p. 53°) were prepared and purified likewise; their m. p.s agree with those recorded in the literature. The purification of the remaining materials was described in Part I.

Phase Diagrams.—These were studied as described previously; the optical method was used throughout, but the regions of special interest, in particular those near the solid–liquid–liquid-crystal triple point, were also studied in detail by the thermal method. The system *p*-azoxyanisole–*p*-dimethylamino-*N*-4-nitrobenzylideneaniline could not be studied by our optical method at high concentrations of the latter since it is so highly coloured.

The results are shown in Tables 1, 2, and 3.

TABLE 1. *Systems studied (component A stated first).*

System no.	Components
1	*p*-Anisic acid (A) with :
	Cinnamic acid
2	*p*-MeO·C_6H_4·CH:N·C_6H_4·OMe-*p* (A) with :
	p-MeO·C_6H_4·CH:N·C_6H_4Me-*p*
	p-Azoxyphenetole (A) with :
4	4 : 4′-Dichloroazoxybenzene
28	β-Naphthylamine
	p-Azoxyanisole (A) with :
3	4 : 4′-Dichloroazoxybenzene
5	*p*-MeO·C_6H_4·CH:N·C_6H_4·NMe_2-*p*
6	4-NO_2·C_6H_4·CH:N·C_6H_4Me-*p*
7	4-NO_2·C_6H_4·CH:N·C_6H_4·OMe-*p*
8	4-Me·C_6H_4·CH:N·C_6H_4·NMe_2-*p*
9	4-Me·C_6H_4·CH:N·C_6H_4·OMe-*p*
10	*p*-MeO·C_6H_4·CH:N·C_6H_4Me-*p*
11	4-Me·C_6H_4·CH:N·C_6H_4Me-*p*
12	4-NO_2·C_6H_4·CH:N·C_6H_4·NMe_2-*p*
13	4-Cl·C_6H_4·CH:N·C_6H_4·OMe-*p*
14	*p*-MeO·C_6H_4·CH:N·C_6H_4Cl-*p*
15	4-Cl·C_6H_4·CH:N·C_6H_4Me-*p*
16	4-Cl·C_6H_4·CH:N·C_6H_4Cl-*p*
17	4-Me·C_6H_4·CH:N·C_6H_4Br-*p*
18	Ph·CH:N·C_6H_4·OMe-*p*
19	4-Me·C_6H_4·CH:NPh
20	Ph·CH:N·C_6H_4·NMe_2-*p*
21	Ph·CH:NPh
22	Azobenzene
23	Azoxybenzene
24	Cinnamic acid
25	Acetanilide
26	α-Naphthylamine
27	β-Naphthylamine

TABLE 2. *Solid–liquid transition temperatures for binary systems. The eutectic temperatures and m. p.s of pure components are direct experimental values: the other temperatures were read from the phase diagrams.*

System no.	Mol. % of component A (see Table 1)											Eutectic A (mol. %)	Eutectic Temp.
	0	10	20	30	40	50	60	70	80	90	100		
1	133·0°	128·2°	120·6°	117·7°	132·8°	143·8°	153·0°	161·3°	169·0°	176·5°	183·8°	27·8	113·0°
2	91·7	90·0	91·0	104·2	113·2	120·4	126·5	132·0	137·2	142·2	147·0	17·8	86·5
3	157·5	150·5	143·5	136·2	128·8	121·0	112·7	103·5	108·3	113·0	118·0	70·0	103·5
4	157·5	150·6	143·6	136·5	129·1	121·0	112·5	119·0	125·1	131·2	137·0	60·0	112·5
5	145·5	140·0	134·1	128·0	121·8	115·5	108·5	100·8	102·3	111·0	118·0	74·5	97·0
6	124·0	118·3	112·3	106·0	99·0	91·0	94·5	101·2	107·2	112·8	118·0	52·5	89·0
7	135·7	130·0	123·8	117·1	109·5	100·8	95·0	101·2	107·2	112·8	118·0	57·0	93·0
8	146·3	140·5	134·5	128·5	121·8	114·0	105·2	104·3	110·0	113·3	118·0	66·5	97·5
9	87·5	82·5	75·8	77·1	86·4	93·7	99·0	103·2	108·0	112·8	118·0	25·0	72·0
10	92·0	89·2	83·8	76·8	86·0	93·6	99·0	103·0	107·4	112·4	118·0	29·8	76·5
11	92·8	87·8	81·8	75·0	86·3	94·0	99·7	104·5	109·0	113·2	118·0	30·0	75·0
12	—	—	—	—	—	—	—	—	112·5	113·0	118·0	—	—
13	124·0	118·7	112·5	105·8	98·7	91·5	98·5	103·0	107·6	112·5	118·0	50·0	91·5
14	93·0	89·3	85·5	81·5	83·3	90·7	97·8	102·7	107·5	112·5	118·0	35·0	79·5
15	128·0	121·5	115·0	108·5	101·5	93·8	100·3	106·3	99·7	113·2	118·0	52·5	91·5
16	112·0	106·5	100·8	94·8	88·3	89·6	98·2	104·8	109·0	113·2	118·0	44·7	85·0
17	133·0	126·8	120·5	113·8	106·8	98·8	98·5	116·5	110·9	113·9	118·0	56·0	93·0
18	71·0	66·5	61·0	77·0	86·4	93·7	99·9	105·0	110·0	114·5	118·0	19·2	58·0
19	45·0	47·0	66·2	78·5	87·7	95·0	101·0	106·0	110·4	114·2	118·0	7·8	40·0
20	100·5	95·0	88·0	79·2	86·8	94·0	100·3	105·5	110·2	114·3	118·0	31·3	78·0
21	52·0	45·0	66·1	79·0	88·9	96·2	102·1	107·0	111·2	114·9	118·0	10·0	45·0
22	68·0	64·0	68·2	78·0	87·5	95·8	102·9	108·7	112·8	115·0	118·0	13·3	61·5
23	36·0	43·2	65·3	78·6	88·0	95·6	101·5	106·7	111·0	115·0	118·0	7·5	32·5
24	133·0	128·2	122·0	114·8	106·7	99·3	107·0	111·5	119·3	116·3	118·0	49·3	98·5
25	114·0	109·7	105·0	99·8	99·5	104·1	107·8	110·6	112·8	114·5	118·0	35·3	97·0
26	50·0	40·2	59·4	72·0	82·8	91·5	100·0	103·0	110·4	112·7	118·0	11·5	37·5
27	110·0	105·1	99·4	92·7	84·0	92·9	99·8	105·5	110·5	115·0	118·0	40·0	84·0
28	110·0	105·5	99·1	94·2	103·9	112·7	120·3	126·7	131·5	134·6	137·0	28·3	92·5

TABLE 3. *Amorphous-liquid–liquid-crystal transition temperatures. The values were read from phase diagrams.*

System no.	Mol. % of component A (see Table 1)											Triple point A	
	40	50	60	70	80	85	90	92·5	95	97·5	100	(mol. %)	Temp.
3	—	—	—	105·3°	115·8°	120·8°	125·8°	128·3°	130·8°	133·0°	135·5°	69·0	104·5°
4	—	—	127·4°	135·6	148·6	153·5	158·5	161·0	163·5	165·7	168·0	52·5	119·0
5	—	—	—	112·7	120·8	124·7	128·5	130·3	132·0	133·8	135·5	62·5	106·5
6	—	96·5°	104·3	112·4	120·3	124·3	128·3	130·2	132·1	134·0	135·5	46·5	94·0
7	115·4°	120·0	124·0	127·5	130·6	132·0	133·4	134·0	134·6	135·2	135·5	35·5	113·0
8	—	—	—	—	110·0	116·3	122·7	126·0	129·2	132·5	135·5	80·0	110·0
9	—	—	—	107·8	117·5	122·2	126·6	128·9	131·0	133·2	135·5	62·5	100·0
10	—	—	—	107·7	117·8	122·5	127·2	129·2	131·4	133·5	135·5	63·0	100·0
11	—	—	—	—	—	113·5	120·9	124·6	128·3	132·0	135·5	82·5	110·0
12	—	—	—	—	126·7	127·7	129·4	130·4	132·3	133·5	135·5	—	—
13	—	—	98·5	108·8	118·0	122·5	126·8	129·0	131·1	133·3	135·5	60·0	98·5
14	—	—	—	107·3	117·2	121·8	126·4	128·6	131·0	133·3	135·5	62·0	99·0
15	—	—	—	—	—	113·8	121·3	125·0	128·6	132·3	135·5	83·0	110·5
16	—	—	—	—	—	114·5	121·8	125·4	129·0	132·3	135·5	81·5	109·5
17	—	—	—	—	—	—	120·0	123·8	127·7	131·5	135·5	85·5	112·5
18	—	—	—	—	—	—	114·5	120·0	125·3	130·4	135·5	90·0	114·5
19	—	—	—	—	—	—	—	116·8	123·8	130·1	135·5	92·0	115·0
20	—	—	—	—	—	—	—	119·0	124·5	130·0	135·5	90·5	114·5
21	—	—	—	—	—	—	—	—	121·2	128·7	135·5	93·2	115·8
22	—	—	—	—	—	—	—	115·5	122·2	129·2	135·5	92·5	115·5
23	—	—	—	—	—	—	—	116·5	123·0	129·7	135·5	92·5	116·5
24	—	—	—	—	—	—	—	119·8	125·4	130·6	135·5	91·0	116·5
25	—	—	—	—	—	—	—	—	121·0	128·3	135·5	93·0	115·0
26	—	—	—	—	—	—	—	—	122·2	129·0	135·5	93·0	116·8
27	—	—	—	—	—	—	—	116·0	123·0	129·3	135·5	92·5	116·0
28	—	—	—	—	—	136·5	147·7	152·7	157·8	162·7	167·5	83·5	133·0

DISCUSSION

Bogojawlensky and Winogradoff (*Z. phys. Chem.*, 1907, **60**, 433; 1908, **64**, 229) studied a number of binary systems in which one or both components could form liquid crystals. In the latter cases they found that the liquid-crystal–normal-liquid transition lines were straight, representing the transition temperatures of a range of "ideal" mixed liquid crystals of varying composition. Since the transition lines were also straight in cases where one component, but not the other, formed liquid crystals, they deduced that in such cases the second component would form a liquid crystal if the liquid could be supercooled sufficiently, and that the corresponding virtual transition temperature could be determined by extrapolation. They confirmed this hypothesis by showing that similar values for the virtual transition temperatures could be obtained by extrapolation in different binary systems (the first component being varied); and also, more dramatically, by studying binary systems in which neither component itself formed liquid crystals, but where the depression of melting point in mixtures should allow them to show mesomorphism. The phase diagrams in such cases had the form predicted from the values for the virtual transition temperatures found by extrapolation in other systems. Similar cases have been reported by Walter (*Ber.*, 1925, **58**, 2303).

We studied the systems *p*-anisic acid–cinnamic acid (no. 1), and *N*-*p*-anisylidene-*p*-anisidine–*N*-*p*-anisylidene-*p*-toluidine (no. 2), in the hope that mixtures of these substances, neither of which itself forms liquid crystals, might show anisotropic behaviour, but this was not observed in either case.

Bogojawlensky and Winogradoff oversimplified the situation since the transition lines are not invariably straight. This will be evident, not only from the examples given in this paper, but also from systems studied previously in other investigations, *e.g.*, the system *p*-azoxyanisole–*p*-methoxycinnamic acid where the transition line shows a strong minimum (Kock, *Z. phys. Chem.*, 1904, **48**, 129). Moreover, we find different values (34° and 71°) for the virtual transition temperature of 4 : 4′-dichloroazoxybenzene depending on whether the second component in the binary system is *p*-azoxyanisole or *p*-azoxyphenetole (nos. 3, 4); this observation can be reconciled with Bogojawlensky and Winogradoff's views only if the unobserved parts of the transition lines bend appreciably—and in that case reliable extrapolation is impossible.

Nevertheless it is probably true that any substance with anisotropic molecules would form a liquid crystal if it could be obtained in liquid form at a sufficiently low temperature. For if the molecules are asymmetric, or if the force fields round them are asymmetric, the internal energy of the liquid would be less if the molecules were all oriented parallel to one another, in an appropriate mutual relationship. In other words, a nematic form of the substance must have a lower energy than the normal amorphous liquid, and this in turn implies that the normal liquid will undergo transition to a nematic form if it is cooled sufficiently. Whether this nematic form can be observed in practice will depend on the melting point of the solid; in most cases the transition will be virtual since it will lie below the melting point.

Consider now a mixture of two different substances, both with asymmetric molecules. In this case two factors will influence the ease of liquid-crystal formation; first, the ability of the molecules to pack into a single liquid-crystal "lattice," and, secondly, the mean orientational cohesive energy density of the mixture (*i.e.*, the decrease in energy on orientation of the liquid). If the two components are of similar size and shape, the steric factors will be uniform for mixtures of all compositions; since the orientational cohesive energy density will vary more or less linearly with composition, the transition line in the phase diagram should be more or less straight. This is certainly the case for mixture of compounds of the type *p*-A·C_6H_4·B·C_6H_4·C-*p*, where B is azo, azoxy, or –CH=N–; all these molecules, for given terminal groups A and C, should be similar in size and shape.

If, however, the molecules of the two components differ, there will be more difficulty in packing them together. The transition temperature should then be less than that predicted for the "ideal" behaviour considered above; the transition line in the phase diagram should then be concave upwards, and when the components differ markedly it should show a minimum. Such behaviour has been observed by Kock (*loc. cit.*) for *p*-azoxyanisole–*p*-methoxycinnamic acid, and clearly the system *p*-azoxyanisole–*p*-anisic acid (Part I, *loc. cit.*) is similar in type.

Our final group of compounds include examples which should have extremely little tendency to form liquid crystals, so that their virtual transition temperatures should be very low indeed. In the binary systems formed by such substances with a liquid crystal (*e.g.*, *p*-azoxyanisole), the transition line should on any basis be very steep. This is what we observe (cf. nos. 24—28); it is not possible here to distinguish between energetic and stereochemical factors since the transition lines can only be observed over a short range of composition.

We have studied a number of systems in which *p*-azoxyanisole is mixed with a second component similar in shape. The argument given above suggests that the slope of the transition line should in such cases be a measure of the virtual transition temperature of the second component, the virtual transition temperature being higher, the lower the slope.

TABLE 4. *Transition-line slopes for compounds of type p-A·C_6H_4·B·C_6H_4·C-p, admixed with* p*-azoxyanisole (in °C per 10% change in molar composition).*

A	B	C	Slope	A	B	C	Slope
H	CH:N	H	29·5	OMe	CH:N	Br	11·0
H	N:N	H	28·0	Cl	N:NO	Cl	10·0
Me	CH:N	H	26·0	OMe	CH:N	Cl	9·5
H	N:NO	H	25·0	Cl	CH:N	OMe	9·0
H	CH:N	NMe_2	23·0	Me	CH:N	OMe	9·0
H	CH:N	OMe	22·0	OMe	CH:N	Me	8·5
Me	CH:N	Br	16·0	NO_2	CH:N	Me	8·0
Me	CH:N	Me	14·5	OMe	CH:N	NMe_2	7·5
Cl	CH:N	Cl	14·5	OMe	CH:N	OMe	4·0
Cl	CH:N	Me	14·5	NO_2	CH:N	OMe	2·5
Me	CH:N	NMe_2	13·0				

Therefore the lower the slope, the greater the tendency of the second component to form a liquid crystal. Table 4 gives values of the slopes for the cases studied by us. First, it will be observed that the slopes are similar for isomeric pairs of Schiff's bases; *e.g.*, *n*-*p*-anisylidene-*p*-chloroaniline, and *N*-4-chlorobenzylidene-*p*-anisidine; that is not surprising, since such pairs of molecules are clearly very similar. Secondly, the presence of two polar

terminal groups is essential for a low value of the slope; the differences between different monosubstituted Schiff's bases are small compared with the differences between any monosubstituted base and any disubstituted base. Thirdly, Table 5 shows that the effects

TABLE 5. *Slopes for various Schiff's bases.*

A =	NO_2	OMe	Me_2N	Me	Cl	Br	H
C = MeO	2·5	4·0	7·5	9·0	9·0	11·0	22·0
C = Me	8·0	9·0	13·0	14·5	14·5	16·0	26·0
Difference	5·5	5·0	5·5	6·0	5·5	5·0	4·0

of terminal groups are approximately additive; one can deduce the order of group efficiency as $NO_2 > OMe > Me_2N > Me > Cl > Br > H$; and one can even ascribe "group slopes," such that the slope for a given compound is expressed closely by a sum of the slope for the terminal groups present (Table 6). This order is the order of decreasing polarity of the groups regardless of sign; and so evidently the main factor is the magnitude of the group dipole,

TABLE 6. *Group slopes for Schiff's bases.*

NO_2	OMe	NMe_2	Me	Cl	Br	H
0·5	2·0	5·6	7·2	7·2	8·9	19·0

and not its direction. The similarity of Me and Cl is interesting; this may be partly a reflection of their similar size. The very large effect of NO_2 is surprising since very few liquid-crystalline nitro-compounds are known; this apparent discrepancy can probably be ascribed to the high melting points of nitro-compounds, their ability to form liquid crystals consequently remaining latent.

One final point emerges. It was suggested by Kock (*loc. cit.*) that depression of liquid-crystal transition temperature by solutes might be used as a method of determining molecular weights. This would be correct in principle only if the solute were almost insoluble in the liquid crystal, the two-component liquid being a mixture of two phases, one containing only the liquid-crystalline component, and the other being a normal liquid containing both components. We showed, however, in our previous paper (*loc. cit.*) that the birefringent two-component liquids are composed of single liquid-crystalline phases. Depression of transition temperature cannot therefore be used as a reliable method of molecular-weight determination, and indeed the systems studied by us show that the molar depression varies from compound to compound.

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The Chemotherapy of Tuberculosis. Part V. Some 5-Amino-benzacridines and -dibenzacridines.*

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5-Amino-9-methyl-1 : 2- and -3 : 4-benzacridine, and 5-amino-1 : 2-8 : 9- and -2 : 3-6 : 7-dibenzacridine have been synthesised from the corresponding acridones, obtained by the Chapman rearrangement and simultaneous thermal cyclisation of 2-methoxycarbonyl-1-aryl *N*-aryl-benzimidates. Attempted preparation of 1 : 2-3 : 4-8 : 9-tribenzacridone failed. Reduction of 9-methyl-1 : 2-benzacridone by sodium in pentyl alcohol gave 1′ : 2′ : 3′ : 4′-tetrahydro-9-methyl-1 : 2-benzacridine. The basic strengths of the aminoacridines have been determined.

THE preparation of 5-amino-9-methyl-1 : 2- and -3 : 4-benzacridine was undertaken to supply strong bases with large planar surface areas, required for work on the relation between physicochemical properties and antituberculous activity.

* Part IV, *J.*, 1953, 1490.

9-Methyl-1 : 2-benzacridone has been obtained previously (Reed, *J.*, 1945, 186) in low yield. Attempted Jourdan–Ullmann reaction of 1-bromo-2-naphthoic acid and *o*-toluidine caused reductive debromination to 2-naphthoic acid (cf. Acheson and Robinson, *J.*, 1953, 232). Preparation of 1-chloro-2-naphthoic acid from 1-hydroxy-2-naphthoic acid (Strohbach, *Ber.*, 1901, **34**, 4158; Cairns and Kermack, *J.*, 1950, 1323) gave poor yields and this route was abandoned.

The Chapman rearrangement (*J.*, 1927, 1743) has been used for the preparation of acridones by Jamison and Turner (*J.*, 1937, 1954) who report one instance of direct thermal cyclisation of the *N*-benzoyl-2-methoxycarbonyldiphenylamine (with loss of methyl benzoate) to give the acridone. This direct synthesis has now been extended to benz- and dibenz-acridones.

Condensation of *N*-α-naphthylbenzimidoyl chloride with the sodium salt of methyl 2-hydroxy-6-methylbenzoate gave 6-methoxycarbonyl-2-methylphenyl *N*-α-naphthylbenzimidate (I) which rearranged and cyclised smoothly to 9-methyl-1 : 2-benzacridone (II). In the conversion of this into 5-chloro-9-methyl-1 : 2-benzacridine the use of chloroform and ice in the final hydrolysis (Bachman and Picha, *J. Amer. Chem. Soc.*, 1946, **68**, 1599) was found unnecessary, the chloroacridine being stable (Albert, " The Acridines," Arnold and Co., London, 1951, p. 26). Amination then gave 5-amino-9-methyl-1 : 2-benzacridine after 1·5 hours; reaction for half this time furnished much of the 5-phenoxy-compound, a known intermediate in this reaction (Dupre and Robinson, *J.*, 1945, 549; Albert, Brown, and Duewell, *J.*, 1948, 1284).

Confirmation of the structure of the acridone was sought by reduction to the known 9-methyl-1 : 2-benzacridine (von Braun and Wolff, *Ber.*, 1922, **55**, 3575) but both zinc dust distillation (Graebe and Lagodzinski, *Ber.*, 1892, **25**, 1733) of 9-methyl-1 : 2-benzacridone and Albert and Royer's method (*J.*, 1949, 1148) were unsuccessful.

Reduction of the acridone with sodium and pentyl alcohol, followed by ferric chloride oxidation (Reed, *J.*, 1944, 679), gave a tetrahydrobenzacridine, which must be 1′ : 2′ : 3′ : 4′-tetrahydro-9-methyl-1 : 2-benzacridine (III) from the similarity of its ultraviolet absorption spectrum (Table 1) to that of acridine (Badger, Pearce, and Pettit, *J.*, 1951, 3199), with the expected bathochromic shift (*ca.* 100 Å) due to the alkyl substituents in the acridine system, and also to that of the carbocyclic analogue 1′ : 2′ : 3′ : 4′-tetrahydro-10-methyl-1 : 2-benzanthracene (Fieser and Hershberg, *J. Amer. Chem. Soc.*, 1938, **60**, 940).

TABLE 1. *Absorption spectra in* 95% *ethanol.*

Substance	$\lambda_{max.}$ (Å)	log ε	$\lambda_{min.}$ (Å)	log ε
1′ : 2′ : 3′ : 4′-Tetrahydro-9-methyl-1 : 2-benzacridine	2585, 3580	5·24, 3·87	3020	3·09
Acridine [a]	2475, 3560	5·29, 4·0	2910	2·88
1′ : 2′ : 3′ : 4′-Tetrahydro-10-methyl-1 : 2-benzanthracene [b]	2585, 3510	5·28, 3·76	3020	2·82
9-Methyl-1 : 2-benzacridone	2780, 2870, 3480	4·78, 4·72, 3·79	3100	3·50
3 : 4-Benzacridine [a]	2780, 2860, 3480	4·78, 4·73, 3·87	3080	3·48

[a] Badger, Pearce, and Pettit, *J.*, 1951, 3199. [b] Fieser and Hershberg, *J. Amer. Chem. Soc.*, 1938, **60**, 940.

Reduction of 9-methyl-1 : 2-benzacridone to the acridine was achieved with sodium amalgam (Clemo, Perkin, and Robinson, *J.*, 1924, 1751).

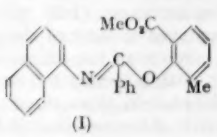
Use of *N*-β-naphthylbenzimidoyl chloride gave the β-naphthyl analogue of the benzimidate (I). This eliminated methyl benzoate to yield 9-methyl-3 : 4-benzacridone, converted, *via* the 5-chloroacridine, into 5-amino-9-methyl-3 : 4-benzacridine. Reduction of the acridone with sodium amalgam furnished the known 9-methyl-3 : 4-benzacridine having a somewhat higher m. p. than that reported (Ullmann, D.-R.P. 123,260; Friedlander, **6**, 462).

Ullmann condensation of 1-bromo-2-naphthoic acid and α-naphthylamine gave only 2-naphthoic acid, but the synthesis of 1 : 2-8 : 9-dibenzacridone (IV) was carried out from 2-methoxycarbonyl-1-naphthyl *N*-α-naphthylbenzimidate (V).

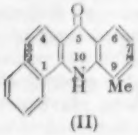
The dibenzacridone (IV) gave a particularly inert chloro-derivative, aminated only at

180°. Sodium amalgam reduction of the acridone gave the known 1 : 2-8 : 9-dibenzacridine (Senier and Austin, *J.*, 1906, 1387).

In order to obtain a 5-aminodibenzacridine unsubstituted in the 1- and the 9-position, preparation of 2 : 3-6 : 7-dibenzacridone was undertaken. This was obtainedfro m 3-methoxycarbonyl-2-naphthyl *N*-β-naphthylbenzimidate (VI), and was converted, *via* the reactive 5-chloro-compound, into 5-amino-2 : 3-6 : 7-dibenzacridine.



(I)



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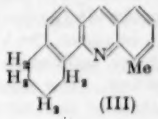

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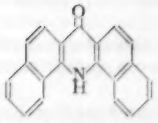

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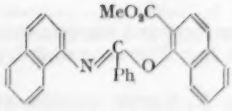

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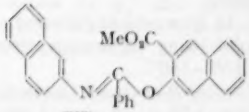

(VI)

Attempted synthesis of 1 : 2-3 : 4-8 : 9-tribenzacridone by condensation of *N*-9-phenanthrylbenzimidoyl chloride with methyl 1-hydroxy-2-naphthoate was unsuccessful.

The relative basic strengths of the foregoing aminoacridines were determined in 50% alcoholic solution by potentiometric titration; the exceedingly low solubility of the bases in water precluded the use of spectrophotometric methods to obtain absolute values. The abnormally low basic strength of 1 : 9-disubstituted 5-aminoacridines has been ascribed (Craig, *J.*, 1946, 534) to steric blocking of protonation, and the reduced basicity of 5-amino-9-methyl-1 : 2-benzacridine and 5-amino-1 : 2-8 : 9-dibenzacridine, compared with their isomers having free 1- and 9-positions, may be due to the same cause.

The antituberculous activities of the aminoacridines were kindly determined by Professor S. D. Rubbo against *Mycobact. tuberculosis* H37Rv *in vitro*, and are recorded in Table 2. It is seen that the weakly basic 5-amino-1 : 2-8 : 9-dibenzacridine had greatly reduced activity; a full account of the bacteriological aspects will be given elsewhere.

TABLE 2. *Ionisation in 50% alcohol at 20°.*

Substance	pK_a	Antituberculous activity [a]
5-Amino-1 : 2-benzacridine	8·15 [a]	256,000
5-Amino-9-methyl-1 : 2-benzacridine	7·26	128,000
5-Amino-3 : 4-benzacridine	8·41 [b]	256,000
5-Amino-9-methyl-3 : 4-benzacridine	8·59	128,000
5-Amino-1 : 2-8 : 9-dibenzacridine	5·36,[c] 5·30 [d]	32,000
5-Amino-2 : 3-6 : 7-dibenzacridine	8·94	256,000

[a] Highest dilution, expressed as 1/molarity, completely inhibiting growth in Youmans's medium after 14 days at 37°, in presence of 10% of serum.

[a] Albert, Goldacre, and Phillips (*J.*, 1948, 2240) find 8·13. [b] *Idem, loc. cit.* [c] In 50% alcohol from half-neutralisation point. [d] In 66% alcohol by potentiometric titration.

EXPERIMENTAL

Methyl 2-Hydroxy-6-methylbenzoate.—This ester had b. p. 124—126°/21 mm., n_D^{20} 1·5350. Behal and Tiffeneau (*Bull. Soc. chim.*, 1908, **3**, 730) give b. p. 111°/11 mm.

2-Methoxycarbonyl-6-methylphenyl N-α-Naphthylbenzimidate.—To a cooled solution of sodium (2·23 g.) in ethanol (110 c.c.) was added methyl 2-hydroxy 6-methylbenzoate (19·5 g.), followed rapidly by *N*-α-naphthylbenzimidoyl chloride (20·6 g.; Just, *Ber.*, 1886, **19**, 979) in dry ether. Reaction began immediately with precipitation of sodium chloride, and the solution was set aside overnight. Removal of solvents *in vacuo* and trituration of the residue (water, then light petroleum) gave the *benzimidate*, crystallising from benzene–light petroleum (b. p. 40—60°) as pale yellow prisms (21·3 g., 70%), m. p. 109·5° (Found: N, 3·8. $C_{26}H_{21}O_2N$ requires N, 3·55%).

9-Methyl-1 : 2-benzacridone.—A vigorous reaction occurred when the foregoing benzimidate (30 g.) was heated to 275°, the temperature rising to 300° and methyl benzoate refluxing. The internal temperature was maintained at 280—300° for 0·75 hr., and the cooled residue then boiled with ethanol (25 c.c.) and filtered hot. The insoluble solid was washed (ethanol, then ether) and purified by Soxhlet extraction with pyridine, giving 9-methyl-1 : 2-benzacridone (14·18 g., 72%), as pale straw-coloured needles, m. p. 274° (Found : N, 5·7. Calc. for $C_{18}H_{13}ON$: N, 5·4%). Reed (*J.*, 1945, 186) gives m. p. 265°.

5-Chloro-9-methyl-1 : 2-benzacridine.—(*a*) 9-Methyl-1 : 2-benzacridone (7·58 g.) and phosphorus oxychloride (50 c.c.) were refluxed for 2 hr. After removal of most of the phosphorus oxychloride *in vacuo*, the viscous residue was poured into a mixture of ice, ammonia solution, and chloroform, sufficient to dissolve the product after 0·5 hr. with a further 0·5 hour's stirring without cooling. The solution was kept alkaline to phenolphthalein throughout. Filtration and distillation of the chloroform layer gave *5-chloro-9-methyl-1 : 2-benzacridine* (6·44 g., 79%) as pale yellow needles, m. p. 156·5° (from benzene) (Found : N, 5·05. $C_{18}H_{12}NCl$ requires N, 5·05%).

(*b*) In a second experiment the chloroform and ice were omitted in the alkaline hydrolysis, the solid being vigorously stirred for 1 hr. Filtration and drying gave a quantitative yield, m. p. 155—156°.

5-Amino-9-methyl-1 : 2-benzacridine.—A stirred solution of 5-chloro-9-methyl-1 : 2-benzacridine (5·32 g.) in phenol (29 g.) was heated to 70° with powdered "AnalaR" ammonium carbonate (3·7 g.) as fast as possible. The solution was stirred at 120° for 1·5 hr. and poured into 10N-sodium hydroxide, and the solid was filtered off and washed. A solution of the crude product in N-acetic acid was adjusted to pH 6 and filtered from a trace of weakly basic material, and the filtrate basified with sodium hydroxide, giving *5-amino-9-methyl-1 : 2-benzacridine* (4·76 g., 82%), crystallising from toluene as yellow prisms, m. p. 148° (decomp.) (rapid heating) (Found : N, 11·15. $C_{18}H_{14}N_2$ requires N, 10·85%). The analytical specimen was dried in the dark at 56°, slow decomposition occurring in light at 100°. The *hydrochloride* crystallised from methanol in yellow needles, m. p. 378° (decomp.) (Found : 9·75. $C_{18}H_{14}N_2,HCl$ requires N, 9·5%).

9-Methyl-5-phenoxy-1 : 2-benzacridine.—(*a*) Treatment of 5-chloro-9-methyl-1 : 2-benzacridine with ammonium carbonate in phenol as described above but for only 0·75 hr. gave 57% of the aminobenzacridine and a weakly basic fraction insoluble in N-acetic acid. This was chromatographed in benzene on alumina and crystallised from alcohol as pale fawn prisms of *9-methyl-5-phenoxy-1 : 2-benzacridine*, m. p. 158—159° (Found : 4·55. $C_{32}H_{17}ON$ requires N, 4·2%). Mixed m. p.s with the chloro- and the amino-benzacridine were 128—138° and 128—135° respectively.

(*b*) A mixture of 5-chloro-9-methyl-1 : 2-benzacridine (2·14 g.), sodium hydroxide (0·46 g.) and phenol (7·2 g.) was heated at 100° for 3 hr., the clear solution poured into 2·5N-sodium hydroxide solution (60 c.c.) and filtered, and the solid washed with water and dried at 120°, to give the phenoxy-compound (2·47 g., 96%), which crystallised from ethyl acetate as fawn-coloured prisms, m. p. 159°, undepressed on admixture with the material obtained as in (*a*).

Attempted Preparation of 9-Methyl-1 : 2-benzacridine.—(*a*) A saturated solution of 5-chloro-9-methyl-1 : 2-benzacridine and toluene-*p*-sulphonylhydrazide in chloroform was treated with dry hydrogen chloride for 10 sec. and the mixture set aside for 7 days. Filtration and washing (alcohol) of the precipitate gave the adduct (37% yield) as a yellow powder. Attempted decomposition of this by Albert and Royer's method (*J.*, 1949, 1148) gave only tar insoluble in N-hydrochloric acid.

(*b*) A suspension of powdered 9-methyl-1 : 2-benzacridone (3·88 g.) in refluxing pentyl alcohol (150 c.c.) was treated with sodium (8·25 g.) in 6 portions, complete dissolution occurring after addition of the first portion. The cold solution was diluted with water (150 c.c.), the pentyl alcohol removed in steam, and the yellow acridan filtered off, suspended in 10N-hydrochloric acid (40 c.c.), and refluxed with excess of ferric chloride for 2 hr. The suspension was neutralised with concentrated ammonia solution and extracted with chloroform. Basic material, taken through 2N-hydrochloric acid and chromatographed on alumina in light petroleum (b. p. 40—60°), crystallised from ethanol as pale yellow needles of *1′ : 2′ : 3′ : 4′-tetrahydro-9-methyl-1 : 2-benzacridine* (1·73 g., 44%), m. p. 64° (Found : C, 87·0; H, 7·0; N, 6·0. $C_{18}H_{17}N$ requires C, 87·4; H, 6·95; N, 5·7%). The *picrate* had m. p. 176—177° (orange needles from ethanol) (Found : N, 11·95. $C_{18}H_{17}N,C_6H_3O_7N_3$ requires N, 11·75%).

(*c*) Reduction of 9-methyl-1 : 2-benzacridone (1·5 g.) with sodium amalgam as described below for 1 : 2-8 : 9-dibenzacridone, and oxidation of the crude acridan with ferric chloride gave

9-methyl-1 : 2-benzacridine (0·58 g., 41%), subliming at 200°/0·5 mm., and crystallising from ethanol as yellow plates, m. p. 114—115° (Found : C, 89·15; H, 5·2. Calc. for $C_{18}H_{13}N$: C, 88·9; H, 5·4%). Von Braun and Wolff (*Ber.*, 1922, **55**, 3675) give m. p. 107°. The picrate formed yellow needles, m. p. 156—157°, from methanol. Von Braun and Wolff (*loc. cit.*) give m. p. 155° and Bun-Hoï (*J.*, 1949, 670) reports m. p. 150—151°.

2-*Methoxycarbonyl*-6-*methylphenyl* N-β-*Naphthylbenzimidate*.—Prepared from methyl 2-hydroxy-6-methylbenzoate (48 g.), *N*-β-naphthylbenzimidoyl chloride (50 g.; Just, *Ber.*, 1886, **19**, 979), and sodium (5·5 g.) in ethanol (270 c.c.), the *benzimidate* (63%) crystallised from benzene–light petroleum (b. p. 60—90°) as prisms, m. p. 120—121° (Found : C, 78·8; H, 5·5. $C_{26}H_{21}O_3N$ requires C, 78·95; H, 5·35%).

9-*Methyl*-3 : 4-*benzacridone*.—The preceding benzimidate (22 g.) gave little acridone at 300°. At 360° in nitrogen reaction took place in 0·5 hr., liberating methyl benzoate. The washed (benzene) *acridone* crystallised from nitrobenzene as yellow needles (5·49 g., 38%), m. p. 264—265° (Found : C, 83·2; H, 5·05; N, 5·45. $C_{18}H_{13}ON$ requires C, 83·35; H, 5·05; N, 5·4%).

5-*Chloro*-9-*methyl*-3 : 4-*benzacridine*.—Reaction of the acridone (4 g.) and phosphorus oxychloride gave the *chloro-acridine* (3·25 g., 76%), crystallising from benzene as yellow needles, m. p. 137° (Found : C, 77·5; H, 4·35; N, 4·95. $C_{18}H_{12}NCl$ requires C, 77·8; H, 4·35; N, 5·05%).

5-*Amino*-9-*methyl*-3 : 4-*benzacridine*.—The preceding chloroacridine (2 g.) was aminated in phenol at 120° for 1·5 hr. in the usual manner. After precipitation of impurities at pH 6, the *aminoacridine* (1·41 g., 76%) crystallised from benzene as red needles, m. p. 182—183° (Found : C, 83·9; H, 5·4; N, 10·8. $C_{18}H_{14}N_2$ requires C, 83·7; H, 5·45; N, 10·85%).

9-*Methyl*-3 : 4-*benzacridine*.—Reduction of 9-methyl-3 : 4-benzacridone (1·4 g.) with sodium amalgam as described below for 1 : 2-8 : 9-dibenzacridone gave, apart from recovered acridone (0·28 g.), the acridine (0·61 g., 58%), crystallising from benzene–light petroleum (b. p. 60—90°) as pale cream needles, m. p. 155° (Found : C, 88·9; H, 5·4; N, 5·3. Calc. for $C_{18}H_{13}N$: C, 88·9; H, 5·4; N, 5·7%). Ullmann (D.-R.P. 123,260; Friedlander, **6**, 462) gives m. p. 143°. The *picrate* formed yellow needles (from acetone), m. p. 289° (decomp.) (Found : C, 60·8; H, 3·4. $C_{18}H_{13}N,C_6H_3O_7N_3$ requires C, 61·0; H, 3·4%).

Methyl 1-*Hydroxy*-2-*naphthoate* (cf. Cameron, Jeskey, and Baine, *J. Org. Chem.*, 1950, **15**, 233).—A mixture of α-naphthol (0·2 mole), anhydrous potassium carbonate (0·4 mole), and solid carbon dioxide (1 mole) was heated in an autoclave (500 c.c.) for 8 hr. at 130—140° (internal). The solid was dissolved in boiling water, the solution filtered, and the acid precipitated from the hot filtrate with 10N-hydrochloric acid, washed (water), and dried (100°), giving 1-hydroxy-2-naphthoic acid (80%), m. p. 192°. Refluxing with methanol and sulphuric acid for 12 hr. gave the methyl ester as prisms, m. p. 78°, from ethanol. Schmitt and Burkard (*Ber.*, 1887, **20**, 2699) give m. p.s 187° and 78° for the acid and ester respectively.

2-*Methoxycarbonyl*-1-*naphthyl* N-α-*Naphthylbenzimidate*.—To a cooled solution of sodium (2·03 g.) in ethanol (100 c.c.) was added methyl 1-hydroxy-2-naphthoate (22 g.), followed rapidly by *N*-α-naphthylbenzimidoyl chloride (19·4 g.), each in dry ether. The *benzimidate* was washed with ethanol and crystallised from benzene as pale yellow prisms (23·17 g., 74%), m. p. 141—142° (Found : N, 3·1. $C_{29}H_{21}O_3N$ requires N, 3·25%).

1 : 2-8 : 9-*Dibenzacridone*.—The preceding benzimidate was heated to 280°, whereupon reaction set in, the temperature rising to 310°. Methyl benzoate was formed, and during 0·5 hr. at 280—300°, the *acridone* (47% yield) was deposited as a solid, crystallising from pyridine (by Soxhlet extraction) as straw-coloured needles, m. p. 331—332° (Found : N, 5·0. $C_{21}H_{13}ON$ requires N, 4·75%).

5-*Chloro*-1 : 2-8 : 9-*dibenzacridine*.—The preceding acridone (6·53 g.), after brief heating with phosphorus oxychloride (45 c.c.), gave the *chloroacridine* (6·45 g., 92%) as yellow needles from benzene, m. p. 240—241° (Found : N, 4·8. $C_{21}H_{12}NCl$ requires N, 4·5%).

5-*Amino*-1 : 2-8 : 9-*dibenzacridine*.—No reaction occurred when 5-chloro-1 : 2-8 : 9-dibenzacridine (2·52 g.) was treated with ammonium carbonate in phenol as described previously, but after 2 hr. at 180° with regular further addition of ammonium carbonate, working up as before gave 5-*amino*-1 : 2-8 : 9-*dibenzacridine* soluble in N-acetic acid and crystallising from benzene as pale yellow needles, m. p. 238—239° (1·72 g., 73%) (Found : C, 85·35; H, 4·8; N, 9·7. $C_{21}H_{14}N_2$ requires C, 85·7; H, 4·8; N, 9·5%).

5-*Phenoxy*-1 : 2-8 : 9-*dibenzacridine*.—(*a*) The material (0·88 g.) insoluble in N-acetic acid in the previous preparation crystallised from ethyl acetate as pale yellow prisms, m. p. 254—255°, of the *phenoxyacridine* (Found : N, 4·0. $C_{27}H_{17}ON$ requires N, 3·8%). (*b*) 5-Chloro-1 : 2-8 : 9-dibenzacridine (0·92 g.), phenol (3 g.), and sodium hydroxide (0·19 g.) were heated at 180°

for 2 hr. Working up as above gave the phenoxyacridine (1·07 g., 100%), m. p. and mixed m. p. identical with the product obtained as in (*a*). Attempted preparation at 100° for 3 hr. gave 92% recovery of unchanged chloro-compound.

1 : 2-8 : 9-*Dibenzacridine*.—1 : 2-8 : 9-Dibenzacridone (1 g.) was dissolved in alcohol (100 c.c.) and water (50 c.c.) by adding sodium hydroxide (0·3 g.) with heating and stirring. Sodium amalgam (60 g.; 2·5%) was added during 1 hr. with stirring at 60°, carbon dioxide being passed through at such a rate that the solution remained slightly alkaline. After a further hour's refluxing with continued stirring, the flow of gas was increased; the acridone was then no longer precipitated. Removal of mercury and dilution with water gave the acridan, oxidised by refluxing with excess of ferric chloride in 3N-hydrochloric acid. Treatment with potassium carbonate and extraction of the dried precipitate with benzene gave the acridine (0·67 g., 71%) as pale cream needles, m. p. 188°, undepressed on admixture with a specimen (m. p. 188°) made by Senier and Austin's method (*J.*, 1906, 1387). These authors give m. p. 185·5° and Kermack, Slater, and Spragg (*Proc. Roy. Soc. Edinburgh*, 1930, **50**, 243) give m. p. 185°. A stable picrate could not be formed, nor could the methosulphate be prepared even in nitrobenzene at 160°. Kermack, Slater, and Spragg (*loc. cit.*) mention this methosulphate but do not describe its preparation or properties.

3-*Methoxycarbonyl*-2-*naphthyl* N-β-*Naphthylbenzimidate*.—Prepared from *N*-β-naphthylbenzimidoyl chloride (58 g.), methyl 3-hydroxy-2-naphthoate (66 g.), and sodium (6 g.) in absolute ethanol (300 c.c.), the *benzimidate* was washed with water and alcohol and crystallised from benzene as pale yellow prisms, m. p. 175° (47·8 g., 51%) (Found: C, 80·7; H, 4·9; N, 3·15. $C_{29}H_{21}O_3N$ requires C, 80·7; H, 4·9; N, 3·25%).

2 : 3-6 : 7-*Dibenzacridone*.—The preceding benzimidate (10 g.) was cyclised at 350—360° during 0·5 hr. and the acridone washed with ether and benzene and crystallised from nitrobenzene as golden-red plates (3·69 g., 54%), m. p. 372° (Found: C, 85·45; H, 4·3. Calc. for $C_{21}H_{13}ON$: C, 85·4; H, 4·45%). Strohbach (*Ber.*, 1901, **34**, 4146) gives m. p. >300°.

10-Ethyl-2 : 3-6 : 7-dibenzacridone, prepared by Strohbach's method (*loc. cit.*), formed yellow needles from acetone, m. p. 204·5—205° (Strohbach, *loc. cit.*, gives m. p. 204·5—205°).

5-*Chloro*-2 : 3-6 : 7-*dibenzacridine*.—The acridone (4 g.) was converted as above into the *chloroacridine* (3·67 g., 86%), crystallising from chloroform as orange needles, m. p. 254—255° (Found: C, 80·1; H, 3·85. $C_{21}H_{12}NCl$ requires C, 80·4; H, 3·85%).

5-*Amino*-2 : 3-6 : 7-*dibenzacridine*.—Amination of the preceding chloroacridine in phenol at 120° for 1 hr., then at 180° for 0·5 hr., gave a product sparingly soluble in N-acetic acid. The *base* (89%) was chromatographed on alumina in chloroform and formed red needles (from chlorobenzene), m. p. 226·5° (Found: C, 85·5; H, 4·75. $C_{21}H_{14}N_2$ requires C, 85·7; H, 4·8%).

5-*Phenoxy*-2 : 3-6 : 7-*dibenzacridine*.—Treatment of the chloroacridine (0·5 g.) with phenol (3 g.) and sodium hydroxide (0·1 g.) at 100° for 1·5 hr gave the *phenoxy-compound* (0·48 g., 81%), crystallising from benzene as yellow prisms, m. p. 253—254° (Found: N, 3·4. $C_{27}H_{17}ON$ requires N, 3·75%).

N-9-*Phenanthrylbenzimidoyl Chloride*.—An equimolecular mixture of *N*-9-phenanthrylbenzanilide (Schmidt and Heinle, *Ber.*, 1911, **44**, 1501) and phosphorus oxychloride was heated at 100—110° for 1 hr. Removal of phosphorus oxychloride *in vacuo* and extraction of the residue with benzene–light petroleum (b. p. 60—80°) gave the *benzimidoyl chloride* as yellow prisms, m. p. 118·5° (Found: N, 4·7. $C_{21}H_{14}NCl$ requires N, 4·45%).

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The Chemotherapy of Tuberculosis. Part VI. Some Derivatives of* iso*Nicotinic Acid.*

By J. Cymerman-Craig and D. Willis.

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N- and *N'*-Methyl-*N*-*iso*nicotinoylhydrazine, and *N*-methyl- and *NN'*-dimethyl-*NN'*-di*iso*nicotinoylhydrazine, have been prepared to test a possible correlation between antituberculous activity and chelating ability in this series.

The reaction of *iso*nicotinoylhydrazine with diketones has been found, in two cases, to give results differing from those of Yale *et al.* (*loc. cit.*); attempted preparation of aminomethyl 4-pyridyl ketone gave only 2 : 5-di-4'-pyridylpyrazine.

The high specific activity of *iso*nicotinoylhydrazine against *Mycobact. tuberculosis* has given rise to a number of hypotheses regarding its mode of action. *iso*Nicotinoylhydrazine is known to form metal complexes (cf. *inter al.*, Albert, *Experientia*, 1953, **9**, 370) and the accompanying fall in pH suggests salt formation *via* a *pseudo*-acid (II). It was therefore of interest to examine *N*-methyl-*N*-*iso*nicotinoylhydrazine which will be unable to form such complexes. At the same time the preparation of *N'*-methyl- and *NN'*-dimethyl-*N*-*iso*nicotinoylhydrazine was investigated.

Methyl *iso*nicotinate and methylhydrazine at 100° gave *N'*-methyl-*N*-*iso*nicotinoylhydrazine (I; $R^1 = R^2 = H$, $R^3 = Me$); use of *iso*nicotinoyl chloride gave the same substance, together with *N*-methyl-*NN'*-di*iso*nicotinoylhydrazine (III; $R^1 = H$, $R^2 = Me$). Meyer and Graf's method (*Ber.*, 1928, **61**, 2202) for the preparation of *iso*nicotinoyl chloride was unsatisfactory; pure material was obtained by treatment of *iso*nicotinoyl chloride hydrochloride (Spath and Spitzer, *Ber.*, 1926, **59**, 1477) with triethylamine. The structure of the derivative (I; $R^1 = R^2 = H$, $R^3 = Me$) was established by its failure to condense with acetone; the parent compound, possessing a primary amino-group, readily undergoes this reaction (Fox and Gibas, *J. Org. Chem.*, 1953, **18**, 983). While this work was in progress Fox and Gibas (*J. Org. Chem.*, 1953, **18**, 994) reported the synthesis of this compound (I; $R^1 = R^2 = H$, $R^3 = Me$) in unstated yield from methylhydrazine and methyl *iso*nicotinate at 130°.

Condensation of *iso*nicotinoyl chloride with *NN*-dimethylhydrazine gave a hygroscopic product [cf. the preparation of *N*-2-furoyl-*NN'*-dimethylhydrazine from *NN*-dimethylhydrazine and 2-furoyl chloride by Yale, Losee, Martins, Holsing, Perry, and Bernstein (*J. Amer. Chem. Soc.*, 1953, **75**, 1933)]. *iso*Nicotinic acid was the only product obtained from this by treatment with aqueous formaldehyde and formic acid, or by hydrochloric acid or aqueous formic acid alone.

No reaction occurred between *NN'*-dimethylhydrazine and methyl *iso*nicotinate under mild conditions, while more vigorous treatment cleaved the hydrazine giving methylamine, *iso*nicotinic acid, and *N'*-methyl*iso*nicotinamide. The latter was synthesised from methyl *iso*nicotinate and methylamine. Attempted preparation of *NN'*-dimethyl-*N*-*iso*nicotinoylhydrazine by reaction of *iso*nicotinoyl chloride with excess of *NN'*-dimethylhydrazine in triethylamine gave tars, while the same reagents with addition of pyridine gave only *NN'*-dimethyl-*NN'*-di*iso*nicotinoylhydrazine, also readily obtained from *NN'*-dimethylhydrazine and 2 mols. of the acid chloride.

To the authors' knowledge, no *N*-substituted *N*-*iso*nicotinoylhydrazine has been reported to date. Attempted methylation of *iso*nicotinoylhydrazine by the Eschweiler–Clarke method (Clarke, Gillespie, and Weisshaus, *J. Amer. Chem. Soc.*, 1933, **55**, 4571) gave only *iso*nicotinic acid, also obtained by using aqueous formic acid alone even at 0°. Yale *et al.* report formylation of *iso*nicotinoylhydrazine by anhydrous formic acid, but a suitable anhydrous solvent to induce *N*-methylation without *N*-formylation could not be found. The desired *N*-methyl-*N*-*iso*nicotinoylhydrazine was, however, obtained *via* its benzylidene

* Part V, preceding paper.

derivatives. Condensation of *N*-methyl-*N'*-4-nitrobenzylidenehydrazine (Brady and McHugh, *J.*, 1922, **1648**) with methyl *iso*nicotinate, in dimethylformamide or without solvent, was unsuccessful; however, reaction with *iso*nicotinoyl chloride readily gave *N*-methyl-*N*-*iso*nicotinoyl-*N'*-4-nitrobenzylidenehydrazine, and the unstable *N*-methyl-*N'*-veratrylidenehydrazine afforded the veratrylidene analogue. Attempted condensation of *iso*nicotinoyl chloride and *N*-*cyclo*hexylidene-*N'*-methylhydrazine (Todd, *J. Amer. Chem. Soc.*, 1949, **71**, 1353) gave intractable tars.

The 4-nitrobenzylidene compound was relatively stable to hydrolysis, hydrochloric acid forming the Schiff's base hydrochloride while 2 : 4-dinitrophenylhydrazine hydrochloride under more drastic conditions gave *iso*nicotinic acid and the derivative of the aldehyde. However, the same reagent readily hydrolysed the veratrylidene analogue, removal of the aldehyde derivative affording *N*-methyl-*N*-*iso*nicotinoylhydrazine dihydrochloride.

In view of the tuberculostatic activity of 5-acetamidothiophen-2-aldehyde thiosemicarbazone (Cymerman-Craig and Willis, *J.*, 1955, 1071) the parent aldehyde was condensed with *iso*nicotinoylhydrazine to give the Schiff's base. Condensation of *iso*nicotinoylhydrazine with several diketones was also examined before the publication by Yale *et al.* (*loc. cit.*) came to hand. Our results are reported in so far as they differ from these authors' findings.

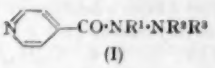
Yale *et al.* report reaction of acetylacetone mono*iso*nicotinoylhydrazone and *iso*nicotinoylhydrazine to give acetylacetone bis*iso*nicotinoylhydrazone, m. p. 254—256°. We found however, that this diketone with *iso*nicotinoylhydrazine (2 mols.) gave only *NN'*-di*iso*nicotinoylhydrazine (m. p. 256°) identical with an authentic sample, while the mother-liquors afforded 3 : 5-dimethylpyrazole. Repetition of the experiment of Yale *et al.* showed that their product was also identical with *NN'*-di*iso*nicotinoylhydrazine, obtained in aqueous or alcoholic solution, and 3 : 5-dimethylpyrazole was also isolated. These two compounds may be formed from the bis-acetylacetone compound (IV) by the changes illustrated.

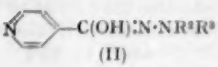
Yale *et al.* report acetonylacetone and *iso*nicotinoylhydrazine as giving solely 2 : 5-dimethyl-1-*iso*nicotinamidopyrrole. We find that acetonylacetone bis*iso*nicotinoylhydrazone is readily obtainable from this reaction, with only a small amount of the pyrrole, arising presumably by internal cyclisation of the monohydrazone first formed. Fission of the bishydrazone occurs readily, on crystallisation from nitrobenzene, on treatment with picric acid, or on heating in ethylene glycol, the products being *iso*nicotinoylhydrazine and 2 : 5-dimethyl-1-*iso*nicotinamidopyrrole. The mechanism of fission may be a preliminary loss of a proton, followed by intramolecular rearrangement and loss of an anion, as shown in (V).

Aminomethyl 4-pyridyl ketone, an analogue of *iso*nicotinoylhydrazine in which the *N*-nitrogen atom is replaced by a methylene group, has been prepared by Burrus and Powell (*J. Amer. Chem. Soc.*, 1945, **67**, 1468) who obtained an unstable dihydrochloride from ethyl hydroxyimino*iso*nicotinoyl acetate. The Neber rearrangement (Neber and Huh, *Annalen*, 1935, **515**, 283; Hatch and Cram, *J. Amer. Chem. Soc.*, 1953, **75**, 38) has been used (Clemo, Holmes, and Leitch, *J.*, 1938, 753) for the synthesis of aminomethyl 2-pyridyl ketone, and the application of this method to methyl 4-pyridyl ketoxime was investigated. The ketoxime was converted into its toluene-*p*-sulphonate which with potassium ethoxide gave an unstable hydrochloride. Attempted liberation of the free base gave only 2 : 5-di-4'-pyridylpyrazine (VI). Formation of 2 : 5-diarylpyrazines from aminomethyl aryl ketones is well known (Neber and Huh, *loc. cit.*; Gabriel, *Ber.*, 1908, **41**, 1127; Burrus and Powell, *loc. cit.*) and the substance (VI) showed ultraviolet absorption resembling that of 2 : 2'-dipyridyl (Gillam, Hey, and Lambert, *J.*, 1941, **364**), with the expected bathochromic shift.

It was of interest to prepare a 4-basically substituted benzoylhydrazine. *p*-Diethylaminobenzoic acid could not be obtained, even under drastic conditions, by Pearl's method (*J. Org. Chem.*, 1947, **12**, 85); it was prepared by Rousset's method (*Bull. Soc. chim. France*, 1894, **11**, 318) and converted, *via* the ester, into *NN'*-di-(*p*-diethylaminobenzoyl)-hydrazine.

The hydrazides were kindly examined by Professor S. D. Rubbo for activity against *Mycobact. tuberculosis* H 37 Rv *in vitro* in presence of 10% of serum. *N*-Methyl-*N'-iso*nicotinoyl- and *NN'*-di*iso*nicotinoyl-hydrazine and its monomethyl derivative had some, though reduced, activity (active at *ca.* M/32,000); Fox and Gibas (*loc. cit.*) report *N*-methyl-*N'-iso*nicotinoylhydrazine to be active *in vivo*. However, while *iso*nicotinoylhydrazine and all Schiff's bases derived from this were active at M/1,200,000—M/4,800,000, *NN'*-dimethyl-*NN'*-di*iso*nicotinoylhydrazine, *N*-methyl-*N-iso*nicotinoylhydrazine, and both


(I)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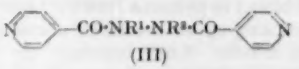
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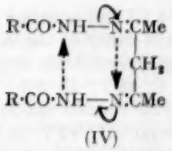
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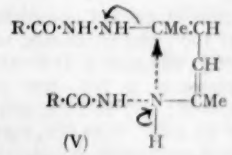
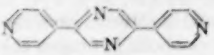

(V)


(VI)

its benzylidene derivatives were virtually inactive (M/250—M/2000). Since the *N*-methyl compounds are incapable of chelation *via* the *pseudo*-acid (II) and give, in fact, neither a colour change nor a precipitate with cupric ion, a direct connection between chelating ability and antituberculous activity in this series appears likely. The bacteriological aspects will be discussed in full elsewhere.

Experimental

iso*Nicotinoyl Chloride.*—*iso*Nicotinoyl chloride hydrochloride (Spath and Spitzer, *Ber.*, 1926, **59**, 1477), from *iso*nicotinic acid (24·6 g.), was distilled from triethylamine (80 g.), giving a red oil, b. p. 80—120°/25 mm., which on redistillation yielded *iso*nicotinoyl chloride (6 g.), b. p. 80°/15 mm.

N-*Methyl*-N'-iso*nicotinoylhydrazine.*—(*a*) Reaction of methylhydrazine (1·84 g.; Hatt, *Org. Synth.*, Coll. Vol. II, **1943**, p. 395) and methyl *iso*nicotinate (2·74 g.) at 100° for 2 hr., followed by concentration *in vacuo*, left a glass from which acetone precipitated *iso*nicotinic acid (0·29 g.). Addition of ether to the acetone-soluble portion gave *N*-methyl-*N'-iso*nicotinoylhydrazine (1·21 g., 40%), m. p. 75—79°, converted into the dihydrochloride, m. p. 226—227° (from methanol) (Found: N, 18·8. Calc. for $C_7H_9ON_3,2HCl$: N, 18·8%). The acetone–ether mother liquors gave the *picrate* (1·64 g., 21·5%), m. p. 173·5—174·5° (decomp.) (from aqueous alcohol) (Found: C, 41·3; H, 3·3; N, 21·9. $C_7H_9ON_3,C_6H_3O_7N_3$ requires C, 41·1; H, 3·2; N, 22·1%). The dioxalate had m. p. 196°. Fox and Gibas (*J. Org. Chem.*, 1953, **18**, 994) report the dihydrochloride, m. p. 225·5—226·5°, and the dioxalate, m. p. 196—197°.

(*b*) *iso*Nicotinoyl chloride (4·85 g.) in dry benzene (25 c.c.) was treated at 20° with methylhydrazine (1·58 g.) in benzene (25 c.c.). The temperature rose to 50°; after 5 minutes' refluxing, evaporation and treatment with acetone gave N-*methyl*-NN'-di*isonicotinoylhydrazine dihydrochloride* (2·4 g., 42%), m. p. 257—258° (from methanol) (Found: C, 47·5; H, 4·45; N, 17·5. $C_{13}H_{18}O_2N_4,2HCl$ requires C, 47·4; H, 4·3; N, 17·0%); the *dipicrate* separated from water as yellow plates, m. p. 252° (Found: C, 42·1; H, 2·55; N, 19·7. $C_{13}H_{18}O_2N_4,2C_6H_3O_7N_3$ requires C, 42·0; H, 2·55; N, 19·6%). The acetone mother-liquors on treatment with alcoholic hydrogen chloride gave *N*-methyl-*N'-iso*nicotinoylhydrazine dihydrochloride (2·26 g., 30%), m. p. and mixed m. p. 225—226°.

Attempted Preparation of NN'-*Dimethyl*-N-iso*nicotinoylhydrazine.*—(*a*) A mixture of *NN'*-dimethylhydrazine (13·5 g.) and methyl *iso*nicotinate (13·7 g.) was heated for 3 hr. at 130° in a sealed tube. Methylamine was evolved, leaving a dark oil from which, after removal of volatile products *in vacuo*, cold ethanolic hydrogen chloride precipitated *iso*nicotinic acid hydrochloride (13·6 g., 80%), m. p. and mixed m. p. 282°. The mother-liquors were made alkaline (ammonia in chloroform) and chromatographed on alumina, giving an oil which with ethanolic hydrogen chloride furnished *N'*-methyl*iso*nicotinamide hydrochloride (1·34 g., 8%), m. p. 206°, converted into the picrate, m. p. 165°, both identical with authentic specimens (see below).

(*b*) A solution of *iso*nicotinoyl chloride hydrochloride (5·34 g., 1 mol.) in pyridine (50 c.c.)

at 50° was slowly added with vigorous stirring to *NN'*-dimethylhydrazine dihydrochloride (8 g., 2 mols.; Hatt, *Org. Synth.*, Coll. Vol. II, 1943, p. 208) in pyridine (50 c.c.) and triethylamine (50 c.c.), and the mixture heated at 100° for 1 hr. Cooling to 0° gave triethylamine hydrochloride which was filtered off, and the filtrate was concentrated, washed with potassium carbonate solution, and extracted with chloroform. Crystallisation from benzene gave *NN'*-dimethyl-*NN'*-di*iso*nicotinoylhydrazine (1 g., 27%), m. p. and mixed m. p. 145—147°.

NN'-*Dimethyl*-NN'-*diisonicotinoylhydrazine*.—*NN'*-Dimethylhydrazine dihydrochloride (2·7 g.) was slowly added with efficient stirring to *iso*nicotinoyl chloride hydrochloride (7·5 g., 2 mols.) in pyridine (100 c.c.) and triethylamine (25 c.c.) at 40°. After 1 hour's heating at 100°, working-up as described above gave NN'-*dimethyl*-NN'-*diisonicotinoylhydrazine* (2·9 g., 54%) as needles (from benzene), m. p. 147° (Found: C, 62·1; H, 5·15; N, 20·4. $C_{14}H_{14}O_2N_4$ requires C, 62·2; H, 5·2; N, 20·7%).

N'-*Methylisonicotinamide*.—Reaction of methyl *iso*nicotinate (2·74 g.) and aqueous methylamine (10 c.c., 30% w/v) for 1 hr. at 100°, and trituration with alcohol–ether of the oil left on removal of solvent, gave the amide (2·6 g., 95%), m. p. 112—113°. The *hydrochloride* crystallised from alcoholic hydrogen chloride as plates, m. p. 205—206° (Found: C, 48·7; H, 5·3; N, 16·3. $C_7H_8ON_2,HCl$ requires C, 48·7; H, 5·25; N, 16·2%), and the *picrate* formed needles (from ethanol), m. p. 165° (Found: C, 42·8; H, 3·05. $C_7H_8ON_2,C_6H_3O_7N_3$ requires C, 42·7; H, 3·05%).

N-*Methyl*-N-*isonicotinoyl*-N'-4-*nitrobenzylidenehydrazine*.—*iso*Nicotinoyl chloride hydrochloride (7·5 g.) in pyridine (75 c.c.) at 50° was added to a well-stirred suspension of *N*-methyl-*N'*-4-nitrobenzylidenehydrazine (7·5 g.; Brady and McHugh, *J.*, 1922, 1652) in triethylamine (50 c.c.) and heated under reflux for 2 hr. The solid *hydrazine* separating on cooling was washed with water and crystallised from pyridine as needles, m. p. 276—277° (8·6 g., 72%) (Found: C, 59·1; H, 4·25; N, 19·8. $C_{14}H_{12}O_3N_4$ requires C, 59·1; H, 4·25; N, 19·7%).

N-*Methyl*-N'-*veratrylidenehydrazine*.—Veratraldehyde (10 g.), methylhydrazine (2·78 g.), and ethanol (30 c.c.) were heated for 3 hr. at 100°. Concentration *in vacuo* and one crystallisation from alcohol afforded the hydrazine (10·1 g., 85%) as prisms, m. p. 95—98°, decomposing rapidly on further purification or storage.

N-*Methyl*-N-iso*nicotinoyl*-N'-*veratrylidenehydrazine*.—The foregoing hydrazine (9 g.), suspended in triethylamine (100 c.c.), was treated with a solution of *iso*nicotinoyl chloride hydrochloride (8·5 g.) in pyridine (100 c.c.) at 50° and left overnight. The solid was filtered off, washed with water and aqueous sodium hydrogen carbonate, and crystallised from methanol as needles, m. p. 163°, of N-*methyl*-N-iso*nicotinoyl*-N'-*veratrylidenehydrazine* (6·4 g., 46%) (Found: C, 64·2; H, 5·75. $C_{16}H_{17}O_3N_3$ requires C, 64·2; H, 5·75%).

N-*Methyl*-N-iso*nicotinoylhydrazine*.—Treatment of the above Schiff's base (1·57 g.) in alcohol (150 c.c.) with 2 : 4-dinitrophenylhydrazine (0·99 g.) in alcoholic N-hydrogen chloride (150 c.c.) at 60° gave veratraldehyde 2 : 4-dinitrophenylhydrazone (1·67 g., 96%), which was removed from the cooled solution after 1 hr. Evaporation *in vacuo* of the filtrate and extraction of the residue with water gave N-*methyl*-N-iso*nicotinoylhydrazine dihydrochloride* (1·1 g., 94%), m. p. 224° (decomp.) (from methanol–chloroform) (Found: C, 37·6; H, 4·95. $C_7H_9ON_3,2HCl$ requires C, 37·5; H, 4·95%).

N-(5-*Acetamido*-2-*thenylidene*)-N'-iso*nicotinoylhydrazine*.—A solution of *iso*nicotinoylhydrazine (0·48 g.) and 5-acetamidothiophen-2-aldehyde (0·59 g.; Cymerman-Craig and Willis, *J.*, 1955, 1071) in boiling methanol (10 c.c.) deposited the *Schiff's base* (0·90 g., 90%) within 10 min., forming from nitrobenzene yellow crystals, m. p. 273—275° (Found: C, 54·0; H, 4·25; N, 19·0; S, 10·8. $C_{13}H_{12}O_2N_4S$ requires C, 54·1; H, 4·2; N, 19·4; S, 11·1%).

Methyl iso*Nicotinate Hydrochloride*.—This hydrochloride crystallised from alcohol as hygroscopic plates, m. p. 143—144°. Ternajgo (*Monatsh.*, 1900, **21**, 451) reports m. p. 257° but was probably dealing with *iso*nicotinic acid hydrochloride.

iso*Nicotinamide Picrate*.—The *picrate* crystallised from aqueous alcohol as yellow needles, m. p. 214—215° (Found: C, 41·2; H, 2·55; N, 19·8. $C_6H_6ON_2,C_6H_3O_7N_3$ requires C, 41·0; H, 2·6; N, 19·9%).

Diacetyl Bisisonicotinoylhydrazone.—Diacetyl (0·86 g., 1 mol.) and *iso*nicotinoylhydrazine (2·74 g., 2 mols.) were refluxed in alcohol (25 c.c.) for 2 hr., giving the bishydrazone (3·07 g., 95%) which, crystallised from methanol (Soxhlet), had m. p. 287° (decomp.) (Found: C, 59·0; H, 5·0. Calc. for $C_{16}H_{16}O_2N_6$: C, 59·25; H, 5·0%). Yale, Losee, Martins, Holsing, Perry, and Bernstein (*J. Amer. Chem. Soc.*, 1953, **75**, 1933) give m. p. >300° (60% yield).

Condensation with Acetylacetone.—(*a*) Acetylacetone (3 g., 3 mols.) and *iso*nicotinoylhydrazine (2·74 g., 2 mols.) were heated under reflux in methanol (12 c.c.) for 30 min. Removal of solvent gave acetylacetone mono*iso*nicotinoylhydrazone (4·2 g., 95%), needles (from ethyl acetate),

m. p. 133° (Found: C, 60·2; H, 5·95; N, 19·4. Calc. for $C_{11}H_{13}O_2N_3$: C, 60·3; H, 6·0; N, 19·2%). Yale *et al.* (*loc. cit.*) give m. p. 131—133° (49% yield).

(*b*) *iso*Nicotinoylhydrazine (2·74 g., 2 mols.) and acetylacetone (1 g., 1 mol.) were refluxed for 2 hr. in ethanol (10 c.c.). The resultant gum, taken up in ethyl acetate, deposited *NN'*-di-*iso*nicotinoylhydrazine (2·1 g., 86%), crystallising from water as needles, m. p. 256°, undepressed on admixture with an authentic sample (Graf, *J. prakt. Chem.*, 1933, **138**, 289) (Found: C, 59·3; H, 4·2; N, 23·3. Calc. for $C_{12}H_{10}O_2N_4$: C, 59·5; H, 4·15; N, 23·1%). The ethyl acetate mother-liquors afforded an oil which on sublimation (100—120°/15 mm.) gave 2 : 5-dimethylpyrazole (0·48 g., 50%), m. p. and mixed m. p. 106° (Knorr and Rosengarten, *Annalen*, 1894, **279**, 237) (Found: C, 62·3; H, 8·0. Calc. for $C_5H_8N_2$: C, 62·5; H, 8·4%).

(*c*) To *iso*nicotinoylhydrazine (0·69 g., 1 mol.) in boiling alcohol (15 c.c.) was added acetylacetone mono*iso*nicotinoylhydrazone (1·1 g., 1 mol.). After 30 min., evaporation furnished recovered *iso*nicotinoylhydrazine (0·46 g.), and the filtrate with ethyl acetate gave *NN'*-di*iso*nicotinoylhydrazine (0·31 g., 26%), m. p. and mixed m. p. 256°. The soluble fraction on sublimation gave 2 : 5-dimethylpyrazole (0·025 g., 5%), identical in m. p. and mixed m. p. with the material described above.

(*d*) Acetylacetone mono*iso*nicotinoylhydrazone (2·19 g., 1 mol.) was heated at 100° with *iso*nicotinoylhydrazine (1·37 g., 1 mol.) in water (20 c.c.) until dissolution was complete. On cooling, *NN'*-di*iso*nicotinoylhydrazine (1·3 g., 53%) separated, having m. p. and mixed m. p. 256°.

Condensation with Acetonylacetone.—(*a*) Acetonylacetone (4·56 g.) was added to a refluxing solution of *iso*nicotinoylhydrazine (11 g.) in ethanol (200 c.c.). After 1 hr., the product which separated crystallised from methanol (Soxhlet), yielding *acetonylacetone bisisonicotinoylhydrazone* (11·1 g., 79%), m. p. 182° (Found: C, 61·0; H, 5·75. $C_{15}H_{20}O_2N_6$ requires C, 61·4; H, 5·7%). The alcoholic solution gave 2 : 5-dimethyl-1-*iso*nicotinamidopyrrole (1·1 g., 13%), crystallising from benzene as needles, m. p. 146° (Found: C, 66·7; H, 6·05. Calc. for $C_{14}H_{13}ON_3$: C, 66·9; H, 6·1%). Yale *et al.* (*loc. cit.*) give m. p. 147—148°.

(*b*) Dissolution of acetonylacetone bis*iso*nicotinoylhydrazone (0·35 g.) in boiling nitrobenzene gave *iso*nicotinoylhydrazine (0·108 g., 79%) (m. p. and mixed m. p.).

(*c*) Reaction of acetonylacetone bis*iso*nicotinoylhydrazone with picric acid gave only *isonicotinoylhydrazine dipicrate*, separating from water as yellow needles, m. p. 185° (Found: C, 36·3; H, 2·45. $C_6H_7ON_3,2C_6H_3O_7N_3$ requires C, 36·5; H, 2·2%).

(*d*) Acetonylacetone bis*iso*nicotinoylhydrazone (1·6 g.) was refluxed in ethylene glycol (10 c.c.) for 5 min. Addition of water and crystallisation of the precipitate from benzene gave 2 : 5-dimethyl-1-*iso*nicotinamidopyrrole (0·4 g., 41%), m. p. and mixed m. p. 145°.

4-Acetylpyridine Oxime.—The oxime crystallised from aqueous alcohol as white laths, m. p. 158° (Found: C, 61·7; H, 6·05. Calc. for $C_7H_8ON_2$: C, 61·7; H, 5·95%). Pinner (*Ber.*, 1901, **34**, 4250) records m. p. 142°.

This (5 g.) in pyridine (10 c.c.) was treated at 0—5° with finely powdered toluene-*p*-sulphonyl chloride (7·65 g.) and set aside for 24 hr. Addition of ice and isolation in the usual manner gave the *ketoxime toluene*-p-*sulphonate* (9·7 g., 90%) as prisms, m. p. 80° (from aqueous alcohol) (Found: C, 57·9; H, 4·85. $C_{14}H_{14}O_5N_2S$ requires C, 57·9; H, 4·85%).

Rearrangement. A solution of potassium (0·49 g.) in ethanol (12 c.c.) was treated with the above toluene-*p*-sulphonate (3·1 g.) in ethanol (8 c.c.) under nitrogen. Potassium toluene-*p*-sulphonate separated almost immediately and was removed (2·12 g., 95%) after addition of ether (160 c.c.) 1 hr. later. Extraction of the ethereal solution with 2N-hydrochloric acid (4 × 40 c.c.), evaporation at <40° of the extracts *in vacuo*, and crystallisation of the residue from methanol gave a hydrochloride (1·15 g.), m. p. 230—235° (decomp.), rapidly darkening in air, on heating, or on attempted recrystallisation. Burrus and Powell (*J. Amer. Chem. Soc.*, 1945, **67**, 1468) record m. p. 240—245° (decomp.) for aminomethyl 4-pyridyl ketone dihydrochloride.

The hydrochloride (0·9 g.), on dissolution in sodium hydrogen carbonate solution and extraction with benzene, gave 2 : *5-di-4'-pyridylpyrazine* (0·02 g.), as prisms, m. p. 231—232°, after sublimation and crystallisation from alcohol (Found: C, 71·3; H, 4·6. $C_{14}H_{10}N_4$ requires C, 71·7; H, 4·3%), showing $\lambda_{max.}$ 2600 (ε 13,200), 3070 (ε 20,400), and $\lambda_{min.}$ 2300 (ε 4000), 2750 A (ε 9550) in EtOH.

Methyl p-*Diethylaminobenzoate.*—Obtained by esterification of *p*-diethylaminobenzoic acid (Rousset, *Bull. Soc. chim. France*, 1894, **11**, 318) with methanol, sulphuric acid, and benzene, the *ester* had m. p. 45—47°, b. p. 94—98°/0·001 mm. (Found: C, 69·8; H, 8·25; N, 6·65. $C_{12}H_{17}O_2N$ requires C, 69·5; H, 8·25; N, 6·75%).

Di-(p-*diethylaminobenzoyl*)*hydrazine.*—The above ester (2 g.), hydrazine hydrate (8 g.,

100%), and 2-ethoxyethanol (5 c.c.) were refluxed for 11 hr. Trituration of the oil with benzene gave *di*-(p-*diethylaminobenzoyl*)*hydrazine* (1·2 g., 69%), crystallising from pyridine as needles, m. p. 267° (Found: C, 69·0; H, 7·85; N, 14·4. $C_{22}H_{30}O_2N_4$ requires C, 69·1; H, 7·9; N, 14·6%)

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The Emission Spectra of Aromatic Hydrocarbons in Crystalline Paraffins at −180°.

By E. J. Bowen and B. Brocklehurst.

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The fluorescence and phosphorescence spectra of coronene, 1 : 12-benzoperylene, perylene, triphenylene, and 9 : 10-dichloroanthracene in crystalline paraffins at −180° are reported. The solvents were *n*-paraffins—pentane, hexane, heptane, octane, and nonane. The splitting of the coronene bands previously reported (Bowen and Brocklehurst, *J.*, 1954, 3875), the intensity of its 0–0 band, and the sharpness and position of the spectra of the other compounds vary markedly with solvent. These effects are due to specific interactions of the solute molecules with the crystal lattice of the solvent, which appear to depend on the relative sizes of the molecules involved.

The absorption and emission spectra of organic compounds become sharper on cooling. In nearly all spectroscopic work at low temperatures, glass-forming solvents (*e.g.*, ether–pentane–alcohol) have been used, but the spectra of solid solutions in crystalline solvents appear to be sharper still (*e.g.*, triphenylmethyl in triphenylamine, Weissman, *J. Chem. Phys.*, 1954, **22**, 155; naphthalene in durene, McClure, *ibid.*, 1954, **22**, 1668).

In a previous paper (Bowen and Brocklehurst, *J.*, 1954, 3875), the fluorescence spectra of coronene and 1 : 12-benzoperylene in several solvents at −180° were described. In light petroleum and alcohol, which form glasses on freezing, both substances have quite sharp fluorescence spectra. In frozen hexane and heptane, the spectrum of benzoperylene becomes still sharper while most of the coronene bands split into doublets separated by about 70 $cm.^{-1}$, as earlier observed by Shpol'skii, Il'ina, and Klimova (*Doklady Akad. Nauk S.S.S.R.*, 1952, **87**, 935). The hexane and heptane used were B.D.H. "aromatic free" petroleum fractions and were thought to form glasses because of the non-homogeneous nature of their molecular constituents, but later work shows that they do in fact crystallise.

Coronene, in frozen mixtures of hexane and heptane containing 30—70% (vol.) of heptane, has a fluorescence spectrum identical with that from light petroleum solution. Outside this composition range, the results can be interpreted in terms of two spectra superimposed, one of doublets and one of singlets. Presumably, two phases are formed—one glassy as given by light petroleum and containing both hexane and heptane, the other crystalline and consisting of hexane or heptane only. That the individual solvents crystallise has been confirmed by the use of purer specimens. When the latter are cooled, white, needle-like crystals are formed (the B.D.H. specimens freeze to transparent blocks) and the spectrum of coronene in them is similar to that from the B.D.H. specimens. Mixtures of hexane and heptane, and light petroleum, also form white masses, because the glass cracks, but no crystals are visible.

In this work, the solvents used were *n*-pentane, -hexane, and -heptane (99% pure) and *n*-octane and -nonane (99·9% pure). These will be called "pure" to distinguish them from the B.D.H. specimens, though the latter merely contain more of similar impurities. A mixture of equal volumes of hexane and heptane (B.D.H.) was used as a convenient glass-forming solvent for comparative purposes. Because supplies of the pure solvents were

limited, most of the measurements on hexane, heptane, and octane solutions were made with the B.D.H. specimens; no difference was found except for coronene, as described below. More detailed measurements have been made on the solvent effects on the fluorescence spectra of coronene and benzoperylene; the fluorescence spectra of perylene and some anthracene derivatives, and the phosphorescence spectra of coronene and triphenylene, have also been studied in the same way.

Experimental

The apparatus was identical with that described previously (Bowen and Brocklehurst, *loc. cit.*). Fluorescent light from the frozen specimen passed through a Hilger constant-deviation glass-prism spectrometer and its intensity was measured by a photomultiplier. Some of the spectra were also recorded photographically with the same apparatus, the photomultiplier being replaced by a camera; this was more convenient for the study of phosphorescence, and wavelengths could be measured more accurately. An iron arc was used for wavelength calibrations. It is estimated that, for narrow bands, wavelengths could be determined to ± 1 Å or better in the blue, and to ± 5 Å in the yellow, the chief limitation being the width of the bands. Further work at lower temperatures would be required for greater precision. Relative intensities on the plates were measured with a microphotometer. The photomultiplier had been calibrated and was used for measurements of the fluorescence in relative quantum units of intensity.

Fluorescence spectra at room temperature were also measured with the spectrometer and photomultiplier. Absorption spectra at room temperature were measured with a Unicam S.P. 500 spectrophotometer; because of the low solubility of coronene, 3-cm. cells were used. The emission of coronene and of triphenylene was excited by the mercury 3135 Å line, and that of the other substances by the mercury 3650 Å line. Concentrations used were approximately 10^{-4}M; more dilute solutions of perylene and the anthracene derivatives (about 10^{-5}M) were used to avoid reabsorption of fluorescence; this was unnecessary for the other compounds.

The specimens of coronene and benzoperylene were prepared as described previously (*idem, loc. cit.*). Anthracene derivatives were synthesised in this laboratory and purified by chromatography. We are grateful to Professor J. W. Cook for the specimen of perylene, to Dr. D. F. Evans for the triphenylene, and to Professor Sir Cyril Hinshelwood and Dr. R. E. Richards for gifts of the paraffin hydrocarbons.

Results and Discussion

Coronene.—The fluorescence spectrum of coronene in B.D.H. heptane has already been published (*idem, loc. cit.*). More peaks have been detected photographically. All the

Table 1. *Fluorescence spectrum of coronene in pure heptane at* −180°.

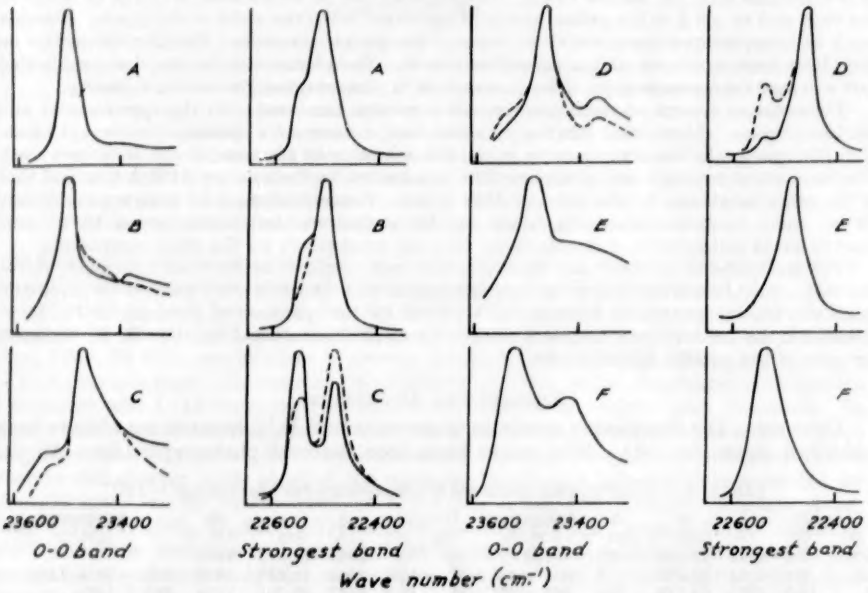
Intensity (*a*)	Intensity (*b*)	λ (Å)	ν′ (cm.⁻¹)	Δν′ (cm.⁻¹)	Assignment (cm.⁻¹)	Intensity (*a*)	Intensity (*b*)	λ (Å)	ν′ (cm.⁻¹)	Δν′ (cm.⁻¹)	Assignmnt (cm.⁻¹)
VW	2·1	4249	23,535	−65	−70?	W	—	4563	21,915	1555	?
W	6·2	4261	23,470	0	0–0 band	M	10·2	4581	21,830	1640	365 − 70 + 1350
S	19·7	4315	23,175	295	365 − 70	M	10·9	4597	21,755	1715	365 + 1350
S	15·7	4328	23,105	365	365	W	7·7	4621	21,640	1830	550 − 70 + 1350
M	—	4338	23,050	420	?	W	7·0	4636	21,570	1900	550 + 1350
W	—	4350	22,990	480	550 − 70	W	—	4649	21,510	1960	685 − 70 + 1350
W	—	4365	22,910	560	550	VW	—	4662	21,450	2020	685 + 1350
W	5·0	4375	22,855	615	685 − 70?	W	—	4685	21,345	2125	850 − 70 + 1350
W	—	4402	22,715	755	825 − 70	W	—	4705	21,255	2215	850 + 1350
W	5·1	4407	22,690	780	850 − 70	S	25·7	4718	21,195	2275	955 − 70 + 1350
W	—	4416	22,645	825	825	S	21·8	4734	21,125	2345	995 + 1350
M	—	4425	22,600	870	850	VW	—	4774	20,945	2525	1155 + 1350?
VS	100·0	4436	22,545	925	995 − 70	W	3·3	4789	20,880	2590	1290 − 70 + 1350?
VS	79·6	4449	22,475	995	995	M	7·8	4824	20,730	2740	1455 − 70 + 1350
W	—	4468	22,380	1090	1155 − 70	M	7·4	4840	20,660	2810	1455 + 1350
W	—	4481	22,315	1155	1155	VW	—	4872	20,525	2945	?
M	10·8	4494	22,250	1220	1290 − 70	M	5·3	4883	20,480	2990	365 − 70 + 2 × 1350
M	—	4509	22,180	1290	1290	M	4·9	4902	20,400	3070	365 + 2 × 1350
S	29·3	4518	22,135	1335	1405 − 70	W	—	4929	20,290	3180	550 − 70 + 2 × 1350
S		4524	22,105	1365	1435 − 70	W		4946	20,220	3250	550 + 2 × 1350
S		4528	22,085	1385	1455 − 70	M	5·4	5042	19,835	3635	995 − 70 + 2 × 1350
S		4532	22,065	1405	1405	M	4·9	5064	19,750	3720	995 + 2 × 1350
W	—	4558	21,940	1530	?						

(*a*) Approximate intensities from photographic plate: S, strong; M, medium; W, weak; V, very.
(*b*) Accurate intensities measured with the photomultiplier and expressed as relative quanta.

peaks, except perhaps the first (4261 Å), occur in pairs. The strong band at 4530 Å consists of three such doublets superimposed. In Table 1, the wavelengths and approximate intensities of the bands emitted by coronene in pure heptane are listed; these values correct and supplement those of Fig. 2 of the reference given.

The transition to the first excited state of coronene is forbidden by symmetry but becomes weakly allowed by coupling with unsymmetrical vibrations (Brocklehurst, *J.*, 1953, 3318) as in the case of benzene (see, *e.g.*, Sponer, Nordheim, Sklar, and Teller, *J. Chem. Phys.*, 1939, **7**, 207). The peculiar behaviour of the first fluorescence band (4261 Å), discussed below, shows that it is the 0–0 band of the transition. All the other bands behave like the strongest band (4436, 4449 Å). Fig. 1 shows the effect of solvent on the first and strongest bands at −180°. These measurements were made with the photomultiplier; photographic measurements resolved the bands in octane and nonane into

FIG. 1. *Effect of solvent on the structure of the coronene fluorescence spectrum in solution at* −180°.



—— Pure solvents; - - - - B.D.H. solvents. *A*, Nonane; *B*, octane; *C*, heptane; *D*, hexane; *E*, pentane; *F*, hexane + heptane.

narrow doublets, and Fig. 2 shows the amount of splitting as a function of solvent chain lengths; negative values correspond to a red shift. The peak positions (at both temperatures) are given relative to the position of the single peak in a mixture of hexane and heptane at −180°. The doublet splitting in a given solvent was the same for all the bands, within the experimental error, and was independent of the purity of the solvent. The room-temperature results are necessarily much less accurate, but the direction of the shift between each pair of solvents is certain from intensity measurements on the sides of the peaks. (The position of the spectrum in a mixture of hexane and heptane at room temperature lies between the positions in the individual solvents.)

At −180° the bands are sharper in crystalline solvents than in the glassy mixture of hexane and heptane. However, the doublet splitting is clearly not due to a mere sharpening of the spectra. The breadth of the bands (apart from the splitting) increases in the order: hexane, heptane, octane, nonane, pentane, glassy solvents. Coronene thus resembles the other substances investigated, but the effect is small.

Fig. 1 shows that the relative intensities of the two components of the doublets are very sensitive to the purity of the solvent. The ordinary B.D.H. "aromatic free" hexane gives an even stronger short-wave component than the special "spectroscopic" grade normally used. The differences are not consistent with an explanation based on partial glass formation by the B.D.H. solvents. Attempts to produce similar effects were made by adding small quantities of paraffinic "impurities" but the results could always be explained in terms of glass formation.

In rigid solvents coronene has a long-lived yellow phosphorescence. Its spectrum in the same series of solvents has been photographed. Results for octane are given in Table 2 (in heptane, doublet splitting leads to considerable overlapping of bands). The vibrational structure is different from the fluorescence, but doublet splitting and solvent "impurity

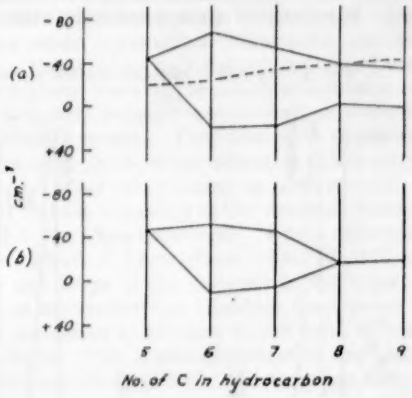


FIG. 2. *Effect of solvent on position of coronene spectra relative to the position in hexane–heptane glass.*

——— at −180°.
– – – – at room temperature.

(*a*) Fluorescence.
(*b*) Phosphorescence.

effects" occur in precisely the same way in hexane and heptane, the doublet splitting being somewhat smaller (Fig. 2). The apparent lack of splitting in octane and nonane may be due to the lower resolving power of the spectrograph in this region. The spectrum in pentane shows no splitting and appears to be distorted relative to that from other solvents

TABLE 2. *Phosphorescence spectrum of coronene in octane at −180°.*

I *	λ (Å)	ν' (cm.$^{-1}$)	$\Delta\nu'$ (cm.$^{-1}$)	Assignment (cm.$^{-1}$)	I *	λ (Å)	ν' (cm.$^{-1}$)	$\Delta\nu'$ (cm.$^{-1}$)	Assignment (cm.$^{-1}$)
W	5154	19,400	0	0–0 band	W	5822	17,175	2225	—
M	5253	19,035	365	365	W	5883	17,000	2400	—
M	5287	18,915	485	—	S	5925	16,880	2520	1160 + 1350
VW	5341	18,720	680	—	S	5946	16,820	2580	1230 + 1350
VW	5366	18,635	765	—	S	6014	16,630	2770	1450 (& 1405) + 1350
W	5389	18,555	845	—	S	6091	16,420	2980	1630 + 1350
W	5425	18,435	965	—	VW	6157	16,240	3160	—
S	5483	18,240	1160	1160	M	6180	16,180	3220	—
S	5503	18,170	1230	1230	M	6277	15,930	3470	—
S	5557	17,995	1405	1405	W	6341	15,770	3630	—
S	5571	17,950	1450	1450	W	6386	15,660	3740	—
VS	5628	17,770	1630	1630	M	6449	15,505	3895	1160 + 2 × 1350
S	5663	17,660	1740	1740	M	6472	15,450	3950	1230 + 2 × 1350
VW	5699	17,545	1855	—	M	6501	15,380	4020	?
VW	5720	17,480	1920	—	M	6546	15,275	4125	1450 (& 1405) + 2 × 1350
S	5783	17,290	2110	—	S	6637	15,070	4330	1630 + 2 × 1350

* Here and in Tables 3 and 4, I = intensity.

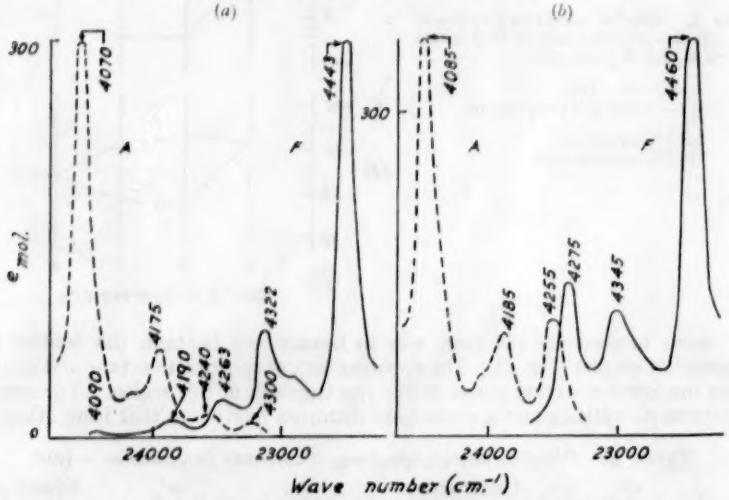
(this also occurs in the fluorescence). No splitting of the 0–0 band could be detected in any solvent but the weak bands on the long-wave side of it vary with solvent as in the fluorescence spectrum.

Because of these very specific solvent effects, it seems certain that the coronene is in true solid solution in the frozen solvents. No separation of solid coronene (which has a diffuse

fluorescence spectrum in the green) was observed. It is surprising that the large coronene molecules fit into the crystal lattices of the paraffins while some smaller aromatic hydrocarbons, *e.g.*, anthracene and naphthalene, will not do so. Formation of associated pairs of coronene molecules seems unlikely; the concentration was very small and the spectrum in heptane was independent of concentration in the range 10^{-4}—10^{-6}M. Associated pairs of pyrene molecules can fluoresce (Förster and Kasper, *Z. phys. Chem., Frankfurt*, 1954, **1**, 275) but their spectrum is a structureless band far removed from the normal fluorescence spectrum. No photochemical changes on prolonged exposure were detected.

An interpretation of the coronene fluorescence spectrum has been given by Sidman (*J. Chem. Phys.*, in the press). He has identified the 4261 Å band as the 0–0 transition; this is confirmed by the effect of solvent on its intensity. Fig. 3 shows parts of the absorption and fluorescence spectra of coronene in hexane and benzene at room temperature. Wavelengths are approximate; the 4263, 4322, and 4443 Å bands in hexane

FIG. 3. *Spectra of coronene at room temperature in (a) hexane and (b) benzene.*



A, Absorption; *F*, fluorescence. (Peak wavelengths given at Å.)

at room temperature correspond to the 4261, 4328, and 4449 Å bands in heptane at −180°. The intensity of the 0–0 band depends on solvent perturbations, while the other bands are little affected by solvent. In carbon disulphide the 0–0 absorption band is actually weaker than in benzene. The feeble 1–0 bands detected in hexane (4090, 4190 Å in fluorescence, 4300 Å in absorption) complete the mirror-image relationship of the absorption and fluorescence spectra; a feeble 1–0 absorption band ($\epsilon_{mol.}$ about 2) can be detected in saturated solution in carbon disulphide. These bands should be temperature-dependent and do not appear in fluorescence at −180°. The previous assignment of the room-temperature bands (Brocklehurst, *loc. cit.*) is clearly incorrect.

The doublet splitting is explained (Sidman, *loc. cit.*) as the removal of the double degeneracy of the unsymmetrical vibrations permitting the transition, by unsymmetrical force fields in the crystalline solvents. The 0–0 band should therefore not split at all. As shown in Fig. 1, in frozen hexane and heptane a weak shoulder (4249 Å) appears on the short-wave side of the 0–0 band and shows the "impurity effect" to some extent, as if this band were also a doublet. This effect is small but it is confirmed by the photographic measurements. The wavelength of the main 0–0 band varies with solvent in just the same way as the long-wave component of the doublets. If the 0–0 band is really a doublet

like the other bands, then the splitting is better explained in terms of two possible environments for the solute within the crystal lattice; *e.g.*, the coronene molecules might lie parallel to or perpendicular to the solvent molecules, if the latter are arranged in parallel rows. If the 0–0 band were much weaker in one environment than in the other, its partial splitting would be accounted for. As would be expected, the stronger 0–0 band is associated with the long-wave component of the doublets. However, it is difficult to see why only two such distinct environments should exist and why the effect is peculiar to coronene. The shoulder on the 0–0 band may be a purely coincidental result of coupling with lattice vibrations.

If the doublet splitting is associated with unsymmetrical vibrations, then all the fluorescence and phosphorescence bands (except the 0–0 bands) are due to coupling with one quantum of any unsymmetrical vibration and 0, 1, or 2 quanta of the symmetrical breathing frequency (1350 cm.$^{-1}$). The other frequencies may be composed of smaller unsymmetrical vibration frequencies plus other symmetrical vibrations; no attempt at further assignment has been made since the infrared and Raman spectra of coronene are not known. The assignments have been given, however, because the intensity changes of the "impurity effect" make it possible to assign frequencies even when only one doublet component could be resolved (*e.g.*, in the 4530 Å group). They also show the interesting comparison between the two spectra. The main symmetrical vibration (1350 cm.$^{-1}$), the first 0–1 band (365 cm.$^{-1}$), and possibly some other bands occur in both spectra; apart from this the two spectra are quite different and the frequency of the strongest fluorescence band (995 cm.$^{-1}$) cannot be detected at all in the phosphorescence. These differences are not peculiar to coronene (see, *e.g.*, benzene; Shull, *J. Chem. Phys.*, 1949, **17**, 295) and are presumably due to differences in the size and shape of the molecule in the triplet state. Despite these differences, the occurrence of unsymmetrical vibration frequencies in the phosphorescence spectrum shows that the transition to the first triplet level is forbidden by symmetry as well as by spin considerations. This is almost certain in any case from the long lifetime of the phosphorescence (McClure, *ibid.*, p. 905); the same has been found to be true for benzene (Shull, *loc. cit.*).

If Sidman's explanation is correct, the extent of the doublet splitting (Fig. 2) must depend on the asymmetry of the force field round the coronene molecule. It is not a simple function of the dispersion forces between solute and solvent which increase, with the increasing polarisability, in the series pentane to nonane (compare the shifting of the spectrum at room temperature). The crystal structures of these paraffins are not known, but the molecules probably lie parallel to their neighbours in two directions and at an angle to those displaced from them along their long axis. A large flat molecule like coronene can easily fit into such a lattice, replacing a few solvent molecules, provided it is not longer than the solvent molecules. Hexane and heptane are about the same length as coronene, octane and nonane are longer, and pentane is shorter. From the marked differences between pentane and hexane, it seems probable that the coronene can fit easily into the lattices of hexane and the larger paraffins but produces considerable distortion of the pentane lattice. Another possibility is that the coronene may be forced to fit into the pentane lattice in a different way.

In the other solvents, if the paraffin molecules lie centrally over the coronene molecule, the terminal methyl groups will be associated with one axis of the coronene molecule. This will provide the asymmetry in the environment which is responsible for splitting the degeneracy of the unsymmetrical vibrations. This asymmetry will decrease as the solvent molecules become longer than the coronene molecule.

The remarkable changes of intensity distribution produced by impurities in a solvent and the differences between different solvents in this respect are not easily explained. The effect of impurities may be to produce changes in the crystal structure of the solvent. Both effects are more easily understood in terms of doublet splitting due to two different possible environments of the coronene molecule. On the other hand, Sidman's explanation gives a more satisfactory picture of the changes in the extent of splitting with solvent; to explain these on the other hypothesis, it would be necessary to postulate that the position of the spectrum of the molecules in one environment showed shifts with change of solvent

in the opposite direction to the position of the spectrum of those in the other environment. This is not impossible, however, since some substances show such shifts in one direction, some in the other (see Fig. 7).

The 0–0 Band.—The effect of solvents in the pentane–nonane series on the intensity of the 0–0 fluorescence band is shown in Fig. 4. At room temperature, there is no significant difference except between pentane and hexane. In pentane, the peak intensity of the 0–0 band is 30% greater than in hexane and the band is also broader (the other bands are not affected). The values for room temperature refer to B.D.H. solvents: the value for the peak intensity ratio for heptane at −180° refers to the stronger doublet peak; it becomes 25% larger if referred to the long-wave peak. At −180° there is a remarkable difference between nonane and octane. In nonane the 0–0 band is very strong and sharp (Fig. 1); in octane the band is much weaker, and thereafter the intensity rises again to pentane. At the same time the breadth of the band becomes greater so that the area of the band is the same in pentane as in nonane. This broadening of the band and the extra peaks on the long-wave side of the band are probably due to coupling with

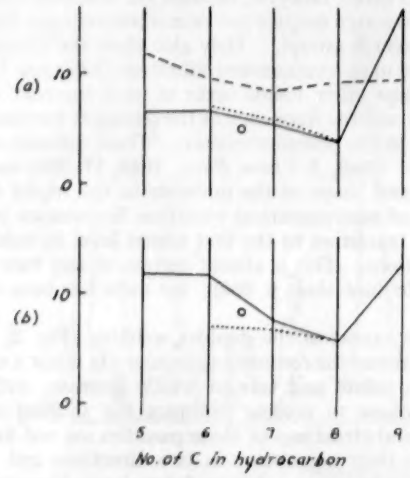


FIG. 4. *Effect of solvent on intensity of the coronene fluorescence 0–0 band.*

(*a*) Peak intensity.
(*b*) band area, relative to main peak (= 100):

——— at −180°, pure solvents.
. . . . at −180°, B.D.H. solvents.
– – – – at room temperature.
O hexane + heptane at −180°.

the acoustic vibrations of the solvent lattice (Gross and Vuks, *J. Phys. Radium*, 1935, **6**, 457; 1936, **7**, 113; Sponer *et al.*, *loc. cit.*; McClure, *J. Chem. Phys.*, 1954, **22**, 1668). For this reason, the peak intensity ratios are perhaps more significant in assessing the solvent's part in permitting the 0—0 band.

The 0–0 band is forbidden by symmetry but becomes weakly allowed if the molecular symmetry is altered by solvent perturbations. However, this asymmetric solvent effect shows no correlation with that responsible for the doublet splitting; nor is there a good correlation with the strength of the ordinary dispersion forces between solute and solvent. The differences between solvents at −180° are clearly associated in some way with their crystal structures. No accurate measurements were made on the intensity of the phosphorescence 0–0 band, but its intensity does not appear to vary much even between octane and nonane. Its structure does vary with solvent—again probably because of coupling with lattice vibrations.

The exceptional behaviour of pentane at room temperature is presumably another result of its being smaller than coronene, but this is surprising since, in the liquid state, paraffins can take on a greater variety of configurations and all would be expected to behave similarly. The intensity of the 0–0 band in hexane is greater at room temperature than at −180° (the relative band areas are 15·3 and 11·4, respectively) and it is greater in fluorescence than in absorption (band area 6·5). The latter effect is due to the greater interaction of the solvent with the more polarisable excited state. Benzene interacts

much more strongly with coronene (band areas : 26·4 in absorption, 42·0 in fluorescence); here, however, some effect of molecular shape or size must be involved since the 0–0 band is weaker in carbon disulphide (21·2 in absorption) despite the larger solvent interaction (shown by the red shift of the spectrum).

Triphenylene.—Since the fluorescence spectrum of this substance was situated in an unfavourable region for the glass spectrograph, measurements were confined to photography of the phosphorescence, which lies in the blue and green. Transitions between the ground state and the lowest excited state (and presumably the first triplet state) are forbidden by symmetry (compare 1 : 3 : 5-trichlorobenzene, Sponer and Hall, Vol. commem. V. Henri, 1947/8, 211, which also belongs to the D_{3h} symmetry group). Coupling with unsymmetrical vibrations must therefore occur, but no doublet splitting was observed. However, this does not invalidate the above interpretation of the splitting of the coronene bands, in view of the highly specific nature of the effect.

The vibrational structure resembles that of the coronene phosphorescence spectrum but is more complicated. There are a larger number of progressions due to coupling with unsymmetrical vibrations, but apparently only one breathing frequency (1350 cm.$^{-1}$). This increased complexity is comparable with that of 1 : 3 : 5-trichlorobenzene (*idem, loc. cit.*). The peaks are grouped in progressions in Table 3. The first six bands are much weaker than the remainder of the spectrum, but they have been tentatively classified with the stronger bands. The position of the 0–0 band is not certain.

TABLE 3. *Phosphorescence spectrum of triphenylene in hexane at* −180° (λ, wavelength in Å).

I	λ	*I*	λ	*I*	λ	*I*	λ	*I*	λ
(W)	(4236)	(W)	(4253)	—	—	(W)	(4283)	—	—
VS	4492	WM	4513	S	4525	VS	4541	VS	4552
M	4780	WM	4808	W	4820	MS	4837	S	4848
		W	5125	VW	5152	VW	5174		
		VW	5506						
	x		*y*		*x*		*x*		*x*
(M)	(4297)	—	—	(M)	(4323)	—	—	(M)	(4347)
S	4561	M	4578	M	4587	S	4594	VVS	4618
S	4858	M	4876			M	4896	VS	4923
M	5194	W	5219			M	5241	MS	5270
						VW	5639		
	y		*y*		*x*		*y*		*x*
VS	4373	M	4398	S	4405	MS	4415	(W)	(4431)
S	4647	M	4672			W	4691	S	4709
S	4950	M	4988					M	5026
MS	5301	M	5336					M	5382
	y		*y*		*x*		*x*		*y*
VW	4440	VW	4446	M	4455	S	4463	S	4484
				W	4739	W	4747	S	4771
				W	5059			M	5096
				W	5427			WM	5463
	x		*x*		*y*		*x*		*y*

One remarkable feature of the spectrum appears to be peculiar to triphenylene; in some progressions the intensity falls off very rapidly, only one, two, or at most, three members of the progression being detectable; in other cases, the intensity falls off slowly in the progression. Accurate measurements of the relative intensities could not be made, but the distinction between the two types of progression is very clear-cut; they are marked *x* and *y* respectively in Table 3. Relative intensities in such progressions are governed by the Franck–Condon principle and depend on the relative sizes of the upper and lower states. The existence of two types of progression may result from the peculiar shape of the triphenylene molecule; one type of unsymmetrical vibration may be associated with a direction in the molecule along which little expansion occurs in the transition to the triplet state, and will then give rise to an *x*-type progression; if, however, an unsymmetrical vibration is associated with a direction where the triplet state is considerably larger than

the ground state, more quanta of the 1350 cm.$^{-1}$ breathing vibration will be excited (y-type progression).

Other Substances.—The spectra of the other substances studied are somewhat sharper in rigid glasses at −180° than at room temperature. In crystalline hexane, however, they are very much sharper, and much fine structure can be resolved. The sharpness falls off rapidly in the approximate order: hexane, heptane, octane, nonane, glassy solvents, pentane (except for benzoperylene). In so far as it can be distinguished from the sharpening effect, no splitting of the bands was observed (with the possible exception of some of the perylene bands); spectra from B.D.H. solvents were identical with those from pure solvents.

The fluorescence spectrum of 1 : 12-benzoperylene in hexane at −180°, measured with the photomultiplier, has been reported previously (Bowen and Brocklehurst, *loc. cit.*). Many more bands can be detected photographically; 74 bands were measured in the spectrum from hexane, but there is more fine structure than can be resolved by our apparatus at this temperature. Therefore only the more prominent bands are given in Table 4. The spectrum is much more complicated than those of the other substances studied; as in the case of chlorobenzene (Sponer and Wollman, *J. Chem. Phys.*, 1941, **9**, 816), which has the same low symmetry (C_{2v}), this is due to the large number of the possible vibrations of an unsymmetrical molecule. It differs from chlorobenzene in that the transition is fully allowed (as is shown by the strength of the first absorption band).

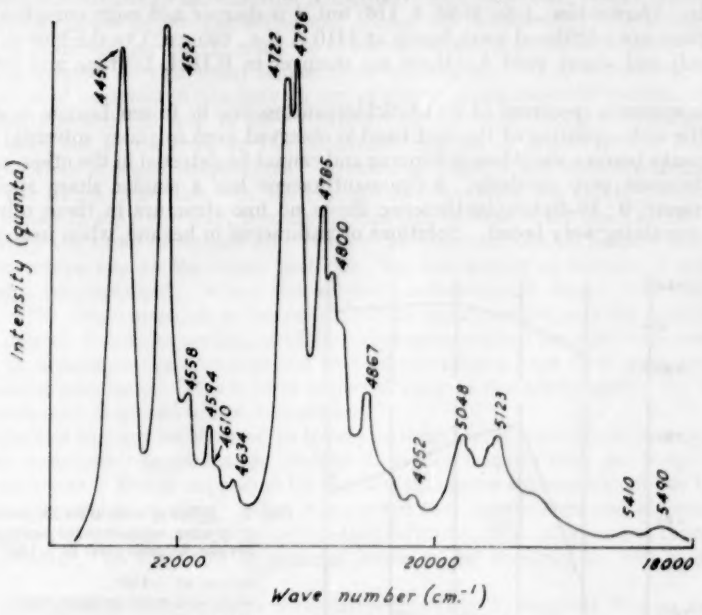
TABLE 4. *Fluorescence spectrum of* 1 : 12-*benzoperylene in hexane and pentane at* −180°.

	Hexane				Pentane		
I	λ (Å)	ν' (cm.$^{-1}$)	$\Delta\nu'$ (cm.$^{-1}$)	I	λ (Å)	ν' (cm.$^{-1}$)	$\Delta\nu'$ (cm.$^{-1}$)
S	4060	24,630	0	S	4049	24,700	0
				W	4054	24,655	35
W	4083	24,490	140	W	4071	24,560	140
				W	4099	24,395	305
M	4121	24,265	365	W	4111	24,325	375
M	4125	24,245	385	W	4114	24,310	390
				W	4119	24,280	420
W	4136	24,175	455				
W	4140	24,155	475	W	4130	24,215	485
				M	4135	24,180	520
S	4149	24,100	530	S	4137	24,170	530
S	4155	24,070	560	M	4144	24,130	570
				S	4146	24,120	580
				M	4151	24,090	610
M	4175	23,950	680	M	4164	24,015	685
VS	4191	23,860	770	VS	4180	23,925	775
S	4198	23,820	810	S	4187	23,885	815
W	4204	23,790	840	W	4192	23,855	845
W	4219	23,700	930	W	4208	23,765	935
M	4222	23,685	945	M	4211	23,745	955
M	4230	23,640	990	M	4218	23,710	990
M	4241	23,580	1050	M	4228	23,650	1050
	25 M and W bands						
				M	4413	22,660	2040
M	4434	22,555	2075	M	4421	22,620	2080
				VW	4429	22,580	2120
M	4451	22,465	2165	M	4439	22,530	2170
				M	4447	22,485	2215
	20 W bands						
W	4715	21,210	3420	VW	4701	21,270	3430
W	4727	21,155	3475	W	4711	21,225	3475
W	4736	21,115	3515				
W	4746	21,070	3560	W	4730	21,140	3560

Unlike all the other substances studied, benzoperylene has an even sharper spectrum in pentane than in hexane; also some new bands appear and others are shifted (Table 4); fewer bands could be resolved than for hexane because of the complexity of the spectrum.

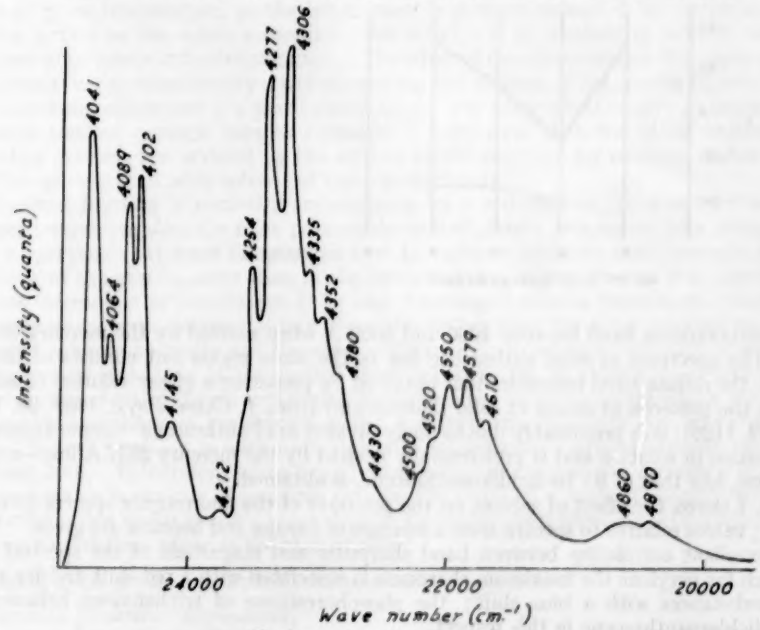
The fluorescence spectrum of perylene in frozen hexane (Fig. 5) is relatively simple (as is to be expected for an allowed transition in a symmetrical molecule). It is also less sharp than those of the larger hydrocarbons. The spectrum indicates coupling with two

FIG. 5. *Fluorescence spectrum of perylene in hexane at −180°.*



(Peak wavelengths given in Å.)

FIG. 6. *Fluorescence spectrum of* 9 : 10-*dichloroanthracene in hexane at −180°.*



(Peak wavelengths given in Å.)

main frequencies; it resembles the absorption spectrum measured in an alcohol glass at −180° (Clar, *Spectrochim. Acta*, 1950, **4**, 116) but it is sharper and more complicated. In heptane, there are additional weak bands at 4410 Å (*i.e.*, 180 cm.$^{-1}$ to the blue of the first strong band) and about 4685 Å; these are stronger in B.D.H. heptane and very weak in octane.

The fluorescence spectrum of 9 : 10-dichloroanthracene in frozen hexane is shown in Fig. 6. The main splitting of the first band is observed even in glassy solvents; most of the small peaks become shoulders in heptane and cannot be detected in the other solvents—perylene behaves very similarly. 9-Cyanoanthracene has a similar sharp spectrum in frozen hexane; 9 : 10-diphenylanthracene shows no fine structure in these solvents, its spectrum remaining very broad. Solutions of anthracene in hexane, when frozen, show a

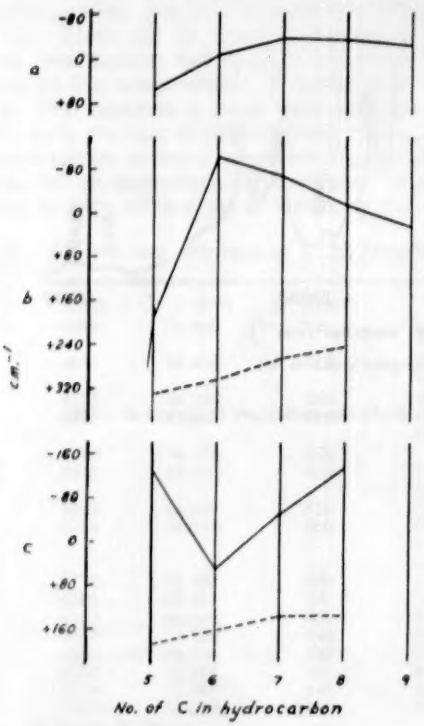


FIG. 7. *Effect of solvent on the position of spectra, relative to the position in hexane–heptane glass at −180°.*

——— at −180°.
– – – – at room temperature.
(*a*) 1 : 12-Benzoperylene.
(*b*) Perylene.
(*c*) 9 : 10-Dichloroanthracene.

broad structureless band between 4000 and 5000 Å when excited by the mercury 3650 Å line. The spectrum of solid anthracene lies in the same region but consists of discrete bands; the diffuse band resembles that obtained by preparing a glassy solution of anthracene in the presence of excess of solid (Moodie and Reid, *J. Chem. Phys.*, 1952, **20**, 1510; 1954, **22**, 1126); it is presumably due to finely divided solid anthracene. Some anthracene does remain in solution and is preferentially excited by the mercury 2537 Å line—a sharp spectrum, like that of 9 : 10-dichloroanthracene, is obtained.

Fig. 7 shows the effect of solvent on the positions of the fluorescence spectra (compare Fig. 2); values relative to spectra from a mixture of hexane and heptane are given. There is an excellent correlation between band sharpness and magnitude of the spectral shift, although for perylene the maximum sharpness is associated with a red shift and for all the other substances with a blue shift; the phosphorescence of triphenylene behaves like 9 : 10-dichloroanthracene in this respect.

Discussion.—Although the effects of non-polar solvents and temperature on fluorescence spectra of substances in liquid solutions and glasses can be explained in terms of dispersion forces, yet more specific effects must be invoked for the crystalline solutions considered here. The solvent shift at room temperature is small and no corresponding changes in sharpness could be detected (the spectra are, of course, much more diffuse than at −180°); measurable spectral blurring is only produced by solvents which interact much more strongly with the solute than do the paraffins. Spectra in glasses at low temperatures are sharper than at room temperature; presumably there is less variation in the environment of the solute molecules. In the crystalline solvents, if the solute molecule can fit into the lattice in only one way, then its spectra will be very sharp since all the molecules have exactly the same environment. If then, as suggested above, hexane molecules are nearest in lattice size to the solute molecule, the appearance of maximum sharpness in hexane can be explained. When the solvent molecules are larger than hexane, the position of the solute molecule in the lattice will be more variable and the spectrum therefore less sharp. Since the spectra of all the substances studied (except benzoperylene) are sharpest in hexane, it must be assumed that all the solutes have their long axes parallel to the solvent molecules. This is to be expected since in this configuration the number of solvent molecules displaced will be a minimum.

The effect of pentane on the spectra is very striking and it must again be supposed that the solute molecules cannot readily fit into its lattice because they are longer than the pentane molecule. This is supported by the fact that some substances tend to be precipitated from pentane on cooling. Also, it appeared that fluorescence and phosphorescence efficiencies are lower in pentane than in the other solvents. The behaviour of benzoperylene is very peculiar; its spectrum in pentane seems to be modified as well as sharpened (Table 4).

The correlation of spectral shifts with sharpening (Fig. 7) suggests that in hexane the interaction between solvent and solute is a minimum; in pentane, the interaction increases because of the distortion of the crystal lattice; in the larger paraffins the dispersion forces will be stronger than in hexane. However, the shift between hexane and nonane is larger than at room temperature, so the latter effect is perhaps enhanced by distortion of the crystal lattice by the solute molecules; this effect will be smallest in hexane, where the the best fit of solute and solvent occurs. The effect of this distortion on the solute molecule apparently varies considerably: the sharpening and shifting of the spectra of perylene and 9 : 10-dichloroanthracene are particularly large; the same effect occurs in coronene but is much smaller, perhaps because coronene is more rigid than the other molecules and therefore is much less affected by the solvent in this respect; for example, it has a much smaller spectral shift with solvent at room temperature.

Spectral blurring is normally accompanied by a red shift of the spectra (because of greater interaction with the more polarisable excited state); this occurs here except in the case of perylene. It must be assumed that the solvent interacts more strongly with the perylene in the ground state than in the excited state. Alternatively, it is possible that solvent interaction is a maximum in hexane (blurring of spectra depends on variations in the interaction with different solute molecules rather than the total interaction). Then perylene behaves normally and the other substances interact more strongly with solvent in the ground state than in the excited state. This might be explicable in terms of the exact arrangement of the solvent molecules around the solute molecule which will depend on its size and shape in the ground state; however, the change of size on excitation is probably very small—it is only 2·5% (linearly) for benzene (Garforth, Ingold, and Poole, *J.*, 1948, 508). It therefore seems more probable that interaction is a minimum in hexane; the anomalous behaviour of perylene may be the result of a marked change of shape on excitation; this seems possible since there is probably much greater conjugation between the two naphthalene nuclei in the excited state.

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The Analysis of Inorganic Compounds by Paper Chromatography. Part VII. A Multiple-spot Phenomenon.*

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Single compounds sometimes give two or more spots on paper chromatograms when mobile phases are used containing an acid different from that corresponding to the anion of the original metal salt. The causes of this phenomenon have been investigated and a detailed account is given of the behaviour of the strontium cation initially present as chloride, nitrate, or acetate with a mobile phase of aqueous butan-1-ol containing acetic acid. Double-spot formation may occur when there is competition for the cation between the original anion and a different anion introduced into the mobile phase, its extent depending upon the concentration and nature of the anion in the mobile phase. Similar double-spot formation can be produced with mobile phases containing a complex-forming agent, *e.g.*, by eluting copper nitrate with a mobile phase containing benzoylacetone.

The production of double zones due to alkaline-earth impurities in the filter paper is also discussed.

It is now well known that single pure substances sometimes give rise to two or more zones on filter paper or cellulose columns. Lester Smith (*Nature*, 1952, **169**, 60), using an aqueous butanol solvent on a kieselguhr column, obtained two solute zones when the butanol was slightly undersaturated with water or contained an excess of water in fine suspension. Consden, Gordon, and Martin (*Biochem. J.*, 1947, **41**, 590) found that metal-salt impurities in paper absorb atmospheric moisture, leading to formation of two zones with amino-acids. Hanes and Isherwood (*Nature*, 1949, **164**, 1107) working with phosphoric esters obtained secondary " ghost " and " shadow " spots which were also attributed to the alkaline-earth and heavy-metal impurities in the paper. These observations led workers in chromatography to pay close attention to (*a*) the purity of the filter paper and (*b*) the water content of partially miscible solvent mixtures.

Many examples are recorded of double-spot formation due to the movement of different species caused by reaction of the original compound with the mobile phase (*e.g.*, Bayley, Bourne, and Stacey, *ibid.*, 1951, **168**, 510; Partridge, *Biochem. J.*, 1948, **42**, 238; Hassall and Martin, *J.*, 1951, 2766). Hahn, Sorkin, and Erlenmeyer (*Experientia*, 1951, **7**, 258) explained the occurrence of three spots when cobalt acetate was run with a solvent containing acetoacetic ester as due to the formation of different " solvated complexes." Erdem and Erlenmeyer (*Helv. Chim. Acta*, 1954, **37**, 2220) similarly recorded three spots for cadmium corresponding to different ammine complexes when the acetate was eluted with a solvent containing propan-1-ol and ammonia. Other examples have been given by Pollard, McOmie, and Elbeih (*J.*, 1951, 466), by Burstall, Davies, Linstead, and Wells (*J.*, 1950, 516), Lederer (*Nature*, 1953, **172**, 727), and Peterson and Reineke (*J. Amer. Chem. Soc.*, 1950, **72**, 3598). Another factor of major importance is the pH of the solvent mixture and of the initial solute solution. Aronoff (*Science*, 1949, **110**, 590) obtained five spots for lysine which were ascribed to different ionic species since the intensity of each spot varied with the pH of the lysine solution; Landua, Fuerst, and Awapara (*Analyt. Chem.*, 1951, **23**, 162) made similar observations for a number of amino-acids. Starting with solutions of potassium or sodium mono- and di-hydrogen phosphates of varying pH values, Curry (*Nature*, 1953, **171**, 1026) obtained separate spots of $H_2PO_4^-$, HPO_4^{2-}, and PO_4^{3-}.

The present paper is mainly concerned with the competition between an added substance and the anion associated initially with the cation.

If, in a chromatographic system, a salt A^+B^- is eluted with a mobile phase containing C^- which can compete with B^- for A^+, then in the process of elution the equilibrium $AB + C^- \rightleftharpoons AC + B^-$ will occur. When the acid H^+C^- is present the

* Part VI, *J.*, 1954, 3435.

tendency to form AC will depend on (*a*) the relative affinities of C and B for A, and (*b*) the relative concentrations of C and B, which in turn depend on the p*K* of the acids HC and HB and hence upon the pH of the mobile phase. Although the cation and the anion of a given salt may sometimes move independently, it has also been shown that they may move as ion pairs, depending on the nature of the eluting solvent.

The work described below has shown that two zones are formed when nitrates or chlorides of cations are eluted with aqueous butanol containing acetic acid, one zone being due to the metal nitrate or chloride and the other to the metal acetate. The relative distribution of cation between the two zones depends on (i) the concentration of the acetate ion in the mobile phase and (ii) the concentration of the chloride ion in the original solution of the metal chloride. Only one zone is obtained when the metal acetate is used as starting material.

When copper nitrate is eluted with aqueous butanol containing benzoylacetone, the tendency of the metal to move as its benzoylacetone complex depends on the concentration of complex-forming agent in the solvent. When the solvent contains nitric acid, a lower proportion of the copper moves as the complex. Under certain conditions of pH and concentration of benzoylacetone copper forms two zones, one of the metal nitrate or possibly the monobenzoylacetone complex $[Cu(C_{10}H_9O_2)]^+NO_3^-$ and the other of the bis-benzoylacetone complex $Cu(C_{10}H_9O_2)_2$. Ferric iron can also give double spots in the above type of solvent mixture (see Pollard, McOmie, and Elbeih, *J.*, 1951, 466) and it was thought that the spot of low R_F value was due to a ferric benzoylacetone complex and the spot of high R_F value to a ferrous one. There is now evidence that part of the iron moves as partially covalent complexes such as $[Fe^{III}(C_{10}H_9O_2)]^{2+}$ or $[Fe^{III}(C_{10}H_9O_2)_2]^+$ just behind the acid front and that part moves as $Fe^{III}(C_{10}H_9O_2)_3$ between the acid front and the liquid front.

For quantitative separations these general considerations are important, and we have found them particularly useful in the selection of suitable solvent mixtures in our recent work.

A double-spot phenomenon distinct from that described above is produced by the presence of alkaline-earth impurity, mainly calcium, in the paper itself. Consider a metal chloride MCl, eluted with aqueous butanol–acetic acid. Calcium as impurity at the site of the salt MCl will partially exchange with the metal. The chloride ions will then move on the paper as MCl and as $CaCl_2$, thereby giving two distinct spots. When the impurities are removed by acid-washing of the paper, only the MCl spot is obtained.

Experimental

Competition between Chloride, Nitrate, and Acetate Ions for Strontium.—The general technique of chromatography was that previously described (Elbeih, McOmie, and Pollard, *Discuss. Faraday Soc.*, 1949, **7**, 183). Whatman No. 1 filter paper was used throughout and strontium was located by the use of sodium rhodizonate.

(a) *Effect of the variation of anion and concentration of cation.* Neutral solutions of varying concentrations of strontium acetate, nitrate, and chloride were eluted with a mobile phase of butan-1-ol (50 ml.), glacial acetic acid (40 ml.), and water (10 ml.). The results are recorded in Fig. 1.

Two zones occurred when two anions were present, and one of these zones corresponded to the position of strontium acetate, while the other zone was due to the nitrate or chloride. The zones due to acetate were the less intense, so that most of the cation had moved under these conditions as the nitrate or chloride. The relative positions and intensities of the zones were unaffected by the initial cation concentration.

(b) *Effect of varying the relative concentrations of chloride and acetate anions in the initial solution.* Mixed solutions of the chloride and acetate of strontium were prepared from the corresponding 0·5N-solutions in the proportions by volume of 10 : 1, 5 : 1, 2 : 1, 1 : 1, 1 : 2, 1 : 5, and 1 : 10 severally. Two spots of each solution were chromatographed with the solvent mixture used in (*a*). One of the spots was sprayed with silver nitrate to detect the chloride ion. The position of the chloride spot was the same as that of the strontium spot of low R_F value.

The results recorded in Fig. 2 show that with a relative decrease in chloride-ion concentration

the intensity of the upper spot due to strontium chloride decreased, being matched by a corresponding increase in the intensity of the lower zone due to strontium acetate.

(c) *Effect of increasing the chloride-ion concentration in the initial solution of strontium chloride.* Solutions of strontium chloride were prepared by mixing 2·5N-strontium chloride (10 ml.), water (5 ml.), and hydrochloric acid (35 ml.). The concentration of the hydrochloric acid used for the preparation was varied by diluting concentrated acid (*d* 1·16) by factors of 1, 2, 4, 8, 16, and 32. Drops of these solutions were chromatographed as before, and the results are recorded in Fig. 3.

At high chloride-ion concentrations the strontium moved as one spot whose R_F value corresponded to that of strontium chloride, but as the chloride concentration decreased the zone became distended and finally divided into two, the second zone corresponding to strontium

Factors affecting the double spotting of strontium.

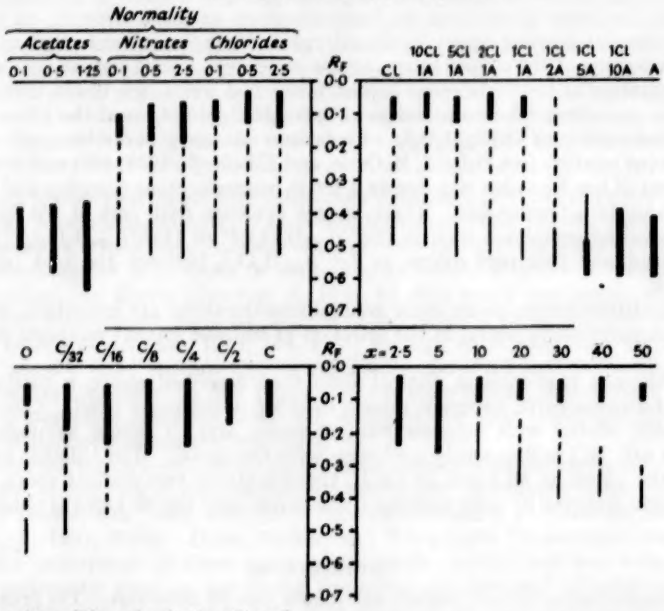

FIG. 1. FIG. 2. FIG. 3. FIG. 4.

FIG. 1. *The nature of the anion in the salt used.*
FIG. 2. *Relative anion concentrations in mixed acetate–chloride solutions.* Cl *and* A *are the relative concentrations of chloride and acetate in each mixture.*
FIG. 3. *The hydrochloric acid content of the chloride solution.* c *is the concentration of* (*d* 1·16) *hydrochloric acid used.*
FIG. 4. *The acetic acid content* (*x* ml.) *of the solvent.*

acetate. Thus only at lower concentrations of chloride ion did the competing power of the acetate ion in the mobile phase have a significant effect.

(d) *Effect of increasing the acetate-ion concentration in the mobile phase.* Spots of a 0·5N-strontium chloride solution were eluted with different mobile phases of increasing acetate-ion concentration prepared from butan-1-ol (50 ml.), water (10 ml.), and glacial acetic acid (*x* ml.), where *x* was 2·5, 5, 10, 20, 30, 40, and 50 severally. The results are recorded in Fig. 4.

With low acetate-ion concentration only one zone was formed but this was rather elongated, stretching down below the position of strontium chloride. As the acetate-ion concentration increased the zone extended further towards the strontium acetate position until it finally divided into two zones at the higher acetate-ion concentrations. Thus with increase in concentration of acetic acid strontium tends to move more as its acetate and less as its chloride.

(e) *Effect of variation of the water content of the mobile phase.* Spots of 0·5N-strontium chloride were eluted with different mobile phases of increasing water content prepared from

butan-1-ol (50 ml.), glacial acetic acid (25 ml.), and water (*x* ml.), where *x* was 0, 1, 2, 5, 10, 20, 30, 40, and 50 severally. Double spots were formed by all the solvent mixtures and hence in this system the phenomenon is not connected with the water content of the mobile phase.

Competition between a Complex-forming Agent (Benzoylacetone) and the Nitrate Ion for Cu^{2+} *and* Fe^{3+}.—In previous papers (Pollard, McOmie, and Elbeih, *J.*, **1951**, **466**; Pollard, McOmie, Stevens, and Maddock, *J.*, **1953**, **1338**) the movement of copper in butan-1-ol containing benzoylacetone and nitric acid was shown to depend on the acidity of the solvent. The spot at R_F *ca.* 0·2 was considered to be the benzoylacetone complex but the present work shows that the dibenzoylacetone complex has R_F *ca.* 0·9. Parts (a) and (b) describe the movement of copper on paper chromatograms and part (c) describes further work on the movement of ferric iron. In part (d) liquid–liquid partition experiments with copper and iron in the above solvent system support this work.

(a) *Effect of variation of benzoylacetone concentration on the movement of copper nitrate.* A 0·25N-solution of copper nitrate was used. Copper was detected on the chromatograms with rubeanic acid.

Spots of copper nitrate were eluted with water-saturated butanol containing 10% (w/v) of benzoylacetone and with other solvents obtained by successive dilution of this with equal volumes of water-saturated butanol. In the absence of benzoylacetone, copper moved exclusively at R_F *ca.* 0·1. That this spot was in fact the nitrate was confirmed by the characteristic blue fluorescence observed under ultraviolet light, when the chromatogram was sprayed with "Nitron." When the benzoylacetone concentration was between 0·05 and 0·1%, the copper formed two spots, moving in part to the solvent front as the characteristic green benzoylacetone complex. At higher concentrations of benzoylacetone, the metal moved exclusively in the complexed form.

(b) *Effect of variation of* pH *of solvent on the movement of copper nitrate.* Solvents were prepared by saturating a 0·5% solution of benzoylacetone in butanol with equal volumes of (i) 0·001N-, (ii) 0·01N-, (iii) 0·1N-, and (iv) N-nitric acid. In elutions of copper nitrate with solvents made from (i) and (ii) the metal moved entirely as the benzoylacetone complex. With (iii) and (iv) most of the copper moved as sharply defined spots at R_F 0·1—0·2. With (iv) only a trace of the metal moved as the benzoylacetone complex.

It is most probable that the spot of low R_F is the copper nitrate although the possibility that the $[Cu(C_{10}H_9O_2)]^+$ complex may be present cannot be excluded.

(c) *Movement of ferric iron on paper chromatograms and on cellulose columns.* When ferric salts were eluted on paper chromatograms with butan-1-ol containing 0·5% (w/v) of benzoylacetone and saturated with N-nitric acid (acid front R_F 0·7) two spots were obtained. The spot at R_F 0·9—1·0 was orange-brown and the elongated spot of lower R_F was maroon. The R_F of the lower spot depended on the initial salt, sulphate giving R_F 0·1—0·3, chloride R_F 0·2—0·35, and nitrate R_F 0·3—0·6. This spot is probably due to complexes of the form $[Fe^{III}(C_{10}H_9O_2)]^{2+}2X$, $[Fe^{III}(C_{10}H_9O_2)_2]^+X$, where $X = NO_3^-$, Cl^- or $\frac{1}{2}SO_4^{--}$. This spot in the acid region immediately gave a blue colour when the dried chromatogram was sprayed with neutral potassium ferrocyanide solution. The spot at R_F 0·9—1·0 in the acid-free region did not give a blue colour with ferrocyanide unless sprayed with dilute mineral acid, and appeared to be due to the fully covalent complex $Fe^{III}(C_{10}H_9O_2)_3$. Ferric salts gave one yellowish spot at low R_F due to the hydrated ion or salt, when eluted with the solvent mixture containing no benzoylacetone.

Further results have been obtained on cellulose columns. When a column was packed with a slurry of cellulose in butan-1-ol and the ferric salt was added to the top and eluted with the butan-1-ol–benzoylacetone (0·5%)–N-nitric acid solvent, zones of different colours were obtained above and below the acid front. The orange-brown zone below the acid front was collected and found to be at pH $\simeq$ 6 while the maroon zone above the acid front was found to be at pH $\simeq$ 2.

A column was packed with the butan-1-ol–benzoylacetone–N-nitric acid solvent mixture and was eluted until the acid front had travelled down the whole column. The ferric salt was then added and eluted with the above solvent mixture and only a maroon zone was obtained, corresponding to the spot of low R_F on paper chromatograms. When a column was packed with butan-1-ol containing only benzoylacetone, and ferric salts were eluted with this solvent, only an orange-brown zone was obtained corresponding to the spot of R_F *ca.* 0·9—1·0 on paper chromatograms.

(d) *Liquid–liquid partition experiments.* Copper and ferric nitrates were separately partitioned in two-phase systems prepared by shaking butan-1-ol containing benzoylacetone with

an equal volume of nitric acid of various normalities. The amount of copper or iron in the phases was approximately determined by the colour of the copper or ferric benzoylacetone complex in the upper phase and the copper or ferric nitrate in the lower phase by using a "Spekker" absorptiometer. The approximate amount of copper or iron in the butanol-rich upper phase increased with (i) increase of benzoylacetone concentration and (ii) decrease of normality of acid. Agreement was obtained for the amount of iron found in the upper phase at equilibrium when starting with ferric nitrate or $Fe^{III}(C_{10}H_9O_2)_3$.

The partition coefficients of copper and iron in the same solvent system were sufficiently different to allow complete separation of the benzoylacetone complexes by only 12 transfers in a simplified counter-current distribution train (after Lathe and Ruthven, *Biochem. J.*, 1951, **49**, 540).

Double-zone Formation with Other Cations.—The chlorides of the metal ions, Na, Cu, Ca, Sr, Ba, Mg, Zn, Cd, Hg, Al, Mn, Fe, Co, Ni, were eluted singly with butan-1-ol, acetic acid, and water (5 : 4 : 1). All these cations, except Ca, Fe, and Hg, gave double zones corresponding to the chloride and acetate. The acetate zone had the greater R_F value, but tailed back to the more compact chloride zone. The identity of the metal chloride spots was confirmed as in section (b), on p. 4332. Mercury moved completely as chloride, which dissociated insufficiently to allow of an exchange of anions. Iron was completely converted into complex by the acetic

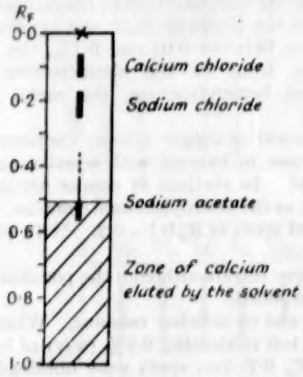

FIG. 5.—*Elution of sodium chloride with butan-1-ol–acetic acid–water* (5 : 4 : 1).

acid, and moved to the solvent front. Failure to detect the less intense calcium acetate spot was obviously due to masking by calcium impurity in the paper. When acid-washed paper was used, all cations except mercuric formed double spots. Therefore, as far as cations were concerned, formation of double-spots appeared to be independent of impurities in the paper. (However, see later reference to iron.)

Double-zone Formation with Anions; *Alkaline-earth Impurities in the Paper.*—In the work described in the preceding section for untreated paper, a well-defined calcium zone, identified with 8-hydroxyquinoline and 4-carboxypyrogallol, was observed in each case (except that of mercury and calcium) at R_F 0·1. The origin of this calcium was obviously the paper itself. The chloride zones of copper, aluminium, sodium, and zinc were well separated from this calcium zone, which was shown on further chromatograms to be calcium chloride. Thus, there were two distinct chloride zones present. Most of the calcium present as impurity in the paper was washed downwards by the solvent, but a certain amount was retained as chloride by anion exchange with the metal chlorides (cf. Fig. 5).

Magnesium is also present in the paper, and moved to the same position as calcium. Mercuric chloride again moved as the undissociated chloride.

When paper was used from which alkaline-earth impurities had been removed by washing with dilute hydrochloric acid, no double chloride zones appeared. With all chromatograms there were faint "secondary" chloride spots which may have been due to traces of heavy metals not removed by acid washing.

Finally, reference must be made to ferric chloride, which gave a single zone of the complex acetate when untreated paper was used, but a chloride and an acetate zone on acid-washed paper. In the former case, chloride ions were removed from the ferric chloride by the calcium in the paper and so all the iron moved as the acetate, thereby appearing at the solvent front.

Conclusions

From this work it is clear that the R_F value of a metal on a chromatogram depends on the anion of the salt used and on the anion(s) or complex-forming agent in the eluting solvent. With certain combinations of these factors multiple spots can be obtained with the metal moving as two or more species.

For quantitative analysis it is essential that a metal should move as a single species and give a compact spot. In the absence of a complex-forming agent this is most simply achieved by starting with salts in which the anion coresponds to the anion of any acid or salt contained in the eluting solvent. In the presence of a complex-forming agent the acidity should be sufficiently low and the concentration of the complex-forming agent sufficiently high to ensure that the metal finally forms a single spot of the complex.

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The Analysis of Inorganic Compounds by Paper Chromatography. Part VIII. The Separation of the Thionic Acids by a New Paper-chromatographic Technique.*

By F. H. Pollard, J. F. W. McOmie, and D. J. Jones.

[Reprint Order No. 6595.]

The effect of a phase boundary on the separation of the thionic acids by use of an organic solvent containing potassium acetate is discussed with particular reference to the problem of double zoning and the formation of two mobile phase-regions on the chromatogram. A new technique is described which eliminates this double zoning, whereby the substances to be separated are placed on the paper after the phase boundary has passed the starting line. A solvent system is suggested for the complete separation of the potassium salts of the thionic acids by means of this technique.

The qualitative separation of thionic acids has already been reported (Pollard, *Brit. Med. Bull.*, 1954, **10**, 191) by use of the solvent system *iso*propanol–acetone–aqueous potassium acetate and the normal downward technique, but some difficulties occurred owing to the formation of double zones for tri- and tetra-thionates when spotted as their potassium salts.

Later work has shown the existence of two phase-regions on the chromatogram, region I extending from the solvent front to an R_F value of *ca.* 0·5, and region II continuing to the solvent feed. The leading phase was acid and free from potassium ions, while the rear phase was alkaline to methyl-orange and contained potassium ions as detected by the lead–cobalt nitrate–sodium nitrite test (Pollard, McOmie, and Stevens, *J.*, 1951, 771).

Both tri- and tetra-thionate gave one zone in each region, no potassium ions being associated with the zones in region I; the latter zones must therefore contain free acids. Potassium penta- and hexa-thionate only appeared on the chromatogram as free acids in region I, while potassium thiosulphate occurred in region II.

Whenever the potassium thionates were chromatographed with the solvent corresponding to region I, double zoning occurred to a varying degree, depending on the thionate species. This was confirmed by running chromatograms in the following ways: (*a*) placing the thionates a long distance from the solvent feed, where region I is large, and ending the run before they were overtaken by region II; (*b*) eluting the thionates with a solvent in which acetic acid replaced potassium acetate, *i.e.*, to simulate the assumed conditions of region I; and (*c*) eluting the thionates with the leading phase corresponding to region I. The latter was prepared by a frontal analysis of the original solvent on a cellulose column.

The zones at lower R_F for each thionate were very well defined and were found to be associated with potassium ions, while no cations could be detected corresponding to the more diffuse zones at high values of R_F. The "acid" zone for thiosulphate and the

* Part VII, preceding paper.

potassium salt zone for pentathionate were of low concentration, and *vice versa*, while each of the double zones for tri- and tetra-thionate appeared roughly equal in concentration.

From these results it appears that, in the leading phase, the free thionic acids are formed by hydrolysis of the salts (hydrogen ions being produced from the acetic acid present) and are removed preferentially from the starting line. The amount of thionate converted into the acid will depend on the strength of the particular thionic acid and on its solubility in the solvent corresponding to region I.

When the moving phase-boundary overtakes the potassium salt zones, all conversion into the free acid is prevented. The position of the phase boundary relative to the solvent front can be quoted without referring to the starting line by measuring the R_P value, where

$$R_P = \frac{\text{distance of phase boundary from solvent feed}}{\text{distance of solvent front from solvent feed}}$$

Such a ratio should be used for defining the position of any fronts or zones when the substance causing the zone is a component of the solvent system. The R_P value for the above solvent system was found to be constant, independent of the length of run, provided the tank was fully equilibrated.

To avoid double zoning due to the above causes, a technique was developed whereby the filter-paper strip is irrigated with solvent until the moving phase-boundary is well past the starting line, whereupon the solutes are placed on the wet paper. It is proposed to call this technique "rear-phase chromatography;" the time of irrigation of the paper before addition of solutes is the pre-elution period, and the time of irrigation after the addition is the chromatographing period.

In this technique, R_F values for the ions cannot be given since the solvent front passes the end of the paper strip. Instead, the absolute distances moved by the ions are quoted in cm. The higher thionates move at a speed approaching that of the solvent front; these species will overtake the phase boundary if the pre-elution period is too short, and they will then produce zones in region I. Conditions for retention of the higher thionates within region II are given in the Experimental section. The distance of starting line from solvent feed is still important, a decrease in this distance being equivalent to a large increase in pre-elution period.

The conditions of rear-phase chromatography are the same as those on a cellulose column washed with solvent to effect equilibration before separation.

Experimental

Apparatus.—For the preliminary work, and the investigation of the formation of the phase boundary, the downward technique was used in conjunction with acid-washed Whatman No. 1 paper (Pollard and Banister, *Analyt. Chim. Acta*, in the press). The apparatus for rear-phase chromatography consists of a modification of the usual frame for supporting chromatograms, whereby two horizontal glass bars, about 1" apart, on the same side of, and parallel to, the solvent trough, and raised about 1" above the horizontal trough supports, replace the glass bar on which the chromatogram would normally rest.

The chromatographic strip is inserted in the solvent mixture (the end in the solvent being weighed down with a glass bar), so that the strip rests over the two glass bars mentioned, with a marked line on the strip in a position between them. This part of the strip is very close to the tank lid, which is provided with a slit ($\frac{1}{8}$" × 6") directly above the marked line. The slit remains covered with a piece of glass during the run, but is uncovered in order to admit the solutes to be separated.

Since the solvent flows off the bottom of the chromatogram in this technique, a filter-paper pad is clipped to the bottom (cf. Westman, Scott, and Pedley, *Chemistry in Canada*, 1952, **4**, 189). Acid-washed paper was unnecessary in rear-phase chromatography, since presumably much of the impurity is washed down the paper before the solutes are chromatographed.

Operating Technique.—The filter-paper strip is marked out with two lines parallel to the top of the strip, the first, 2 cm. from the top where an upward fold is made, the second, a distance d from this line, where d depends on the dimensions of the apparatus. In two apparatus used, d was 5 cm. and 7 cm. severally. When the paper strip is placed with the top end in the trough

as described above, the second line should be about midway between the two parallel bars. The smaller the value of d, the less pre-elution period is necessary.

In order to obtain a reproducible R_F value, about 10 hours' equilibration of the tank with the solvent mixture in the trough is found necessary before the paper is eluted. If only short equilibration times are used, the R_F value is greater than with true equilibration owing to the more rapid evaporation of region I.

After equilibration, the filter-paper strip is placed in the tank as described above, and is eluted for a length of time sufficient for the phase boundary to have moved the required distance past the starting line.

To mark the position of the phase boundary during the run, an indicator was added to the solvent system. Two indicators, bromocresol-purple and phenol-red, had sufficiently high R_F values and convenient pH ranges (5·2—6·8 and 6·8—8·4, respectively) for this purpose.

The prepared solutions of the solutes are then "spotted" on the wet paper at the marked starting line through the slit in the tank lid by means of glass capillary tubes. The slit is then re-covered, and the chromatogram eluted for a certain length of time. During the elution, colourless spots due to the water from the solute solutions are visible against the indicator-coloured background, moving with a velocity similar to that of the solvent front and hence overtaking the phase boundary after a while.

Samples.—Potassium tri-, tetra-, and penta-thionates were prepared by the methods of Goehring *et al.* (Stamm, Goehring, and Feldmann, *Z. anorg. Chem.*, 1942, **250**, 226; Goehring and Feldman, *ibid.*, 1948, **257**, 223). Potassium hexathionate was prepared by Weitz and Achterberg's method (*Ber.*, 1928, **61**, 399). The samples of potassium tri-, tetra-, and penta-thionate were *ca.* 97% pure, and the potassium hexathionate sample was about 90%, the only impurity being potassium chloride. Chromatographic analysis has shown that these samples do not contain detectable amounts of thionates other than the desired preparation. B.D.H. potassium thiosulphate monohydrate was also used.

0·1N-Solutions of each substance were freshly prepared, also a comprehensive mixture, 0·1N with respect to each component. Precipitated sulphur appeared in the mixture after a short time, owing to the catalysing action of thiosulphate on the decomposition of thionates in aqueous solution. Large quantities of penta- and tetra-thionate were detected in the hexa-thionate solution after about 12 hr., but the penta- and tetra-thionate solutions remained without appreciable decomposition for about 3 days (cf. Goehring, Helbing, and Appel, *Z. anorg. Chem.*, 1947, **254**, 189).

Owing to the paper's being wet when the solutes are spotted, the amount of solution to use cannot be gauged by the size of the spot produced. For qualitative purposes, the solutes were drawn into melting-point tubes (approx. diameter 1 mm.), and the tubes held in contact with the pre-eluted paper for about 3 sec.

Development.—The dried chromatograms are sprayed with 0·5N-silver nitrate solution, and warmed, whereupon the unstable silver salts of all these acids decompose, giving a brown stain of silver sulphide and sulphur. In order to keep the chromatograms, they are then washed in concentrated thiosulphate solution and finally in water, to remove all excess of silver as the complex thiosulphate. The sensitivity of the test is greatly increased by viewing the dried chromatograms under ultraviolet light (7×10^{-6} g. of thionate over 0·5 cm.^{2} of the developed spot is clearly visible).

Results.—For a photograph of the separation of thiosulphate and thionates by the normal downward technique see Pollard (*loc. cit.*). This shows the double spotting of tetrathionate and the single acid spots obtained for penta- and hexa-thionate. As the amount of double spotting and also R_F values depend on the distance of starting line from the solvent feed, R_F values will not be quoted for this separation.

The solvent finally selected for use with the rear-phase technique was: *tert.*-butanol (15 ml.), acetone (65 ml.), water (20 ml.), potassium acetate (0·5 g., anhydrous): a higher percentage of potassium acetate led to the decomposition of the higher thionates during the chromatographic run.

With phenol-red in this solvent (0·1%), the R_F value was determined in two different tanks by noting the distances travelled by the phase boundary and the solvent front before the latter reached the clipped pad. After an equilibration period of 10 hr., the values at 17—20° were: tank A, $d = 7$ cm., $R_F = 0{\cdot}39 \pm 0{\cdot}03$; tank B, $d = 5$ cm., $R_F = 0{\cdot}38 \pm 0{\cdot}03$.

The following Table gives distances moved (cm.) by the thio-salts in tanks A and B for: equilibration period = 10 hr., pre-elution period = 24 hr., chromatographing period = 15 hr. The distances of phase boundary from the starting line were: tank A, 26·5 cm., tank B, 31·2 cm.

This distance is measured from the starting line here in order to enable easier comparison of its position with those of other zones.

	Tank A, d = 7 cm.					Tank B, d = 5 cm.				
	S_3O_3''	S_3O_6''	S_4O_6''	S_5O_6''	S_6O_6''	S_3O_3''	S_3O_6''	S_4O_6''	S_5O_6''	S_6O_6''
Tail	2·3	9·5	12·1	14·4	16·9	1·5	8·5	12·0	14·7	18·4
Head	3·8	11·1	14·3	16·0	19·7	2·5	10·1	13·9	16·1	21·4

The separation of the higher thionates may be enhanced either by using a longer run, combined with a long pre-elution period, or by adjusting the length of time of pre-elution and chromatographing so that these species (*i.e.*, penta- and hexa-thionate) move past the phase boundary. For example, in tank B, with 7·5 hours' pre-elution and 15 hours' chromatographing, the phase boundary came between tetra- and penta-thionate, the head and tail movements being:

	S_3O_3''	S_3O_6''	S_4O_6''	S_5O_6''	Phase boundary
Tail	0·5	9·1	16·2	21·5	18·7
Head	2·1	11·5	18·6	24·8	

showing 3 cm. separation between S_4O_6'' and S_5O_6'' instead of 1 cm. as in tank B (first table).

In another run, tetra-, penta-, and hexa-thionate all passed the phase boundary, giving a good separation:

	S_3O_3''	S_3O_6''	S_4O_6''	S_5O_6''	S_6O_6''	Phase boundary
Tail	0·8	11·5	20·5	27·2	33·6	20·5
Head	1·8	13·1	23·5	30·5	36·5	

(Tank B; 7 hours' equilibration, 14 hours' pre-elution, 22·5 hours' chromatographing.)

Thus, by varying the lengths of pre-elution and chromatographing, the separation between any two components may be made greater by the interposition of the phase boundary. Another advantage of the method when applied to these compounds is that no decomposition (as detected by the appearance of zones other than that for the pure thionate spotted) occurs owing to drying the spots on the chromatogram before elution. With the older technique, this occurred except when the chromatogram was placed into the solvent with the spots still wet.

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THE UNIVERSITY, BRISTOL. [*Received, July 11th*, 1955.]

The Infrared Spectra of Some Pyridones and Quinolones and Their Behaviour in the Kolbe–Schmitt Reaction.

By J. A. GIBSON, W. KYNASTON, and A. S. LINDSEY.

[Reprint Order No. 6559.]

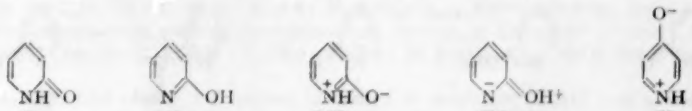
The cyclic amido-structure of 2-pyridone, 6-methyl-2-pyridone, 2-quinolone, and 4-methyl-2-quinolone in the solid state and in solution has been confirmed by infrared measurements. The spectra of sodium 2-pyridyl oxide and potassium 2-quinolyl oxide have also been examined and a chelated structure for potassium 2-quinolyl oxide is suggested to explain its inertness in the Kolbe–Schmitt reaction.

IT is well known that the pyridones and analogous compounds are tautomeric with respect to the keto and the enol forms. For 2-pyridone these are represented by (I) and (II) respectively, probably being stabilised by resonance with the dipolar forms (III) and (IV).

Following Auwers (*Ber.*, 1930, **63**, 2111) and Arndt (*ibid.*, p. 2963), Specker and Gawrosch (*ibid.*, 1942, **75**, 1338) showed by a study of the ultraviolet absorption spectra that in methanolic solution 2- and 4-pyridone exist substantially in the amido-form. Addition of alkali led to marked spectral changes which were ascribed to a change towards the enol form. The spectrum of 3-hydroxypyridine, however, was not greatly affected by either alkali or acid. Leis and Curran (*J. Amer. Chem. Soc.*, 1945, **67**, 79), on the basis of the dipole moment for a dioxan solution, concluded that in this solvent 4-pyridone

existed mainly in the pyridone form with an appreciable contribution from the dipolar form (V).

Although the infrared spectra of solid 3-hydroxy- and of 1-methyl-3-hydroxy-4-pyridone have been reported (Adams, Jones, and Johnson, *J. Amer. Chem. Soc.*, 1947, **69**, 1810) no information on the structure of the solid pyridones has been previously recorded. We have measured the infrared spectra of 2-pyridone, 6-methyl-2-pyridone and 3-hydroxypyridine



(I) (II) (III) (IV) (V)

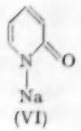
in Nujol and in potassium chloride discs (Hales and Kynaston, *Analyst*, 1954, **79**, 702), and the first two compounds as saturated and dilute solutions in chloroform and carbon tetrachloride. Both 2-pyridone (1571, 1600, 1645, and 1670 cm.$^{-1}$) and 6-methyl-2-pyridone (1543, 1612, 1657, and 1676 cm.$^{-1}$) as solids show bands in the 6-μ region which bear similarities to those exhibited by the pyrimidones and are indicative of the amido-structure. Thus Short and Thompson (*J.*, 1952, 168) have found that 1 : 4-dimethyl-2-methylthiopyrimid-6-one has strong bands near 1596, 1651, and 1685 cm.$^{-1}$, whilst pyrimid-2-one has bands at 1620 and 1650 and pyrimid-4-one at 1605, 1660, and 1680 cm.$^{-1}$ (all as solids in Nujol). These investigators suggested that in the case of pyrimid-2-one one of these absorption bands arises from a carbonyl group of the lactam form, a second arising through an increase in value of the ring vibration localised in the C=N band owing to changes in the bond character resulting from the ketonisation. Absorption bands similar to those reported for the simple *N*-monosubstituted amides (Richards and Thompson, *J.*, 1947, 1248) are shown by 2-pyridone at 1571 and 1645 cm.$^{-1}$, these shifting in solution to 1540 and 1658 cm.$^{-1}$. 6-Methyl-2-pyridone behaves similarly. The possibility that intermolecular hydrogen bonding in the pyridones gives rise to the doublet around 1650 and 1670 cm.$^{-1}$ can be disregarded since dissolution in chloroform and carbon tetrachloride and dilution caused no shift or change in the intensity of those bands.

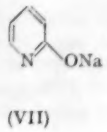
The evidence from the 3-μ region is inconclusive. Weak bands between 3100 and 3400 cm.$^{-1}$ are present in the spectra of the pyridones but cannot be regarded as definite proof of the presence of an amide group (cf. Short and Thompson, *loc. cit.*, p. 184). A stronger band near 3050 cm.$^{-1}$ probably arises from the aromatic C–H linkage since pyridine itself has an absorption band in this region. The spectrum of 3-hydroxypyridine shows the hydroxyl group to be present in bonded form since it has a very broad band centred at about 2430 cm.$^{-1}$. Presumably both OH $\cdots$ O and OH $\cdots$ N intermolecular bonding exist and this accounts for the wide spread of the absorption. The absence of strong absorption bands over the range 1600—1700 cm.$^{-1}$ confirms the absence of any possible keto-structure as with 2-pyridone. The insolublity of 3-hydroxypyridine in carbon tetrachloride and chloroform precluded measurement of the effects of dilution on the broad 2430 cm.$^{-1}$ band.

Ewing and Steck (*J. Amer. Chem. Soc.*, 1946, **68**, 2181), on the basis of ultraviolet absorption spectra, have also shown that 2- and 4-quinolones exist essentially in the amido-form in neutral or acid media. We have further confirmed those observations by studying the infrared spectra of 2-quinolone and 4-methyl-2-quinolone as solids and in solution. Both compounds show bands arising from an amido-structure and analogous to those observed for 2-pyridone. Thus 2-quinolone (solid) has bands at 1547, 1595, 1638, and 1654 cm.$^{-1}$, and in chloroform solution at 1553, 1605, and 1660 cm.$^{-1}$; 4-methyl-2-quinolone (solid) has bands at 1545, 1600, and 1644 cm.$^{-1}$, and in chloroform solution at 1548, 1605, and 1653 cm.$^{-1}$.

We have also examined the spectra of sodium 2-pyridyl oxide and of potassium 2-quinolyl oxide in the solid state. The structure of each of these compounds can be considered as the resonance hybrid of the various possible forms. Thus in the case of sodium 2-pyridyl oxide, if intermolecular chelation is assumed absent, contributions can be expected

from the completely covalent structures such as (VI) and (VII), and various ionic species such as (VIII), (IX), (X), and (XI). Neither of the two metal compounds mentioned shows absorption arising from a carbonyl group and this suggests that structure (VI) and its variants do not appreciably contribute toward stabilisation. Interaction of a positive sodium with nitrogen will however reduce the ionising tendency of the oxygen–sodium linkage and the overall behaviour of sodium 2-pyridyl oxide would appear best represented


(VI)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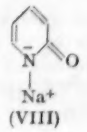
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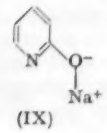
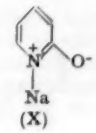

(IX)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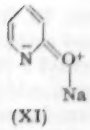
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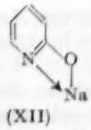
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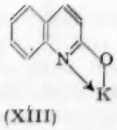
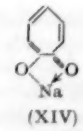

(XIII)


(XIV)

by structure (XII), in which weak chelation occurs between nitrogen and sodium. Rising temperature would presumably increase this interaction. Similarly potassium 2-quinolyl oxide can be represented by structure (XIII). Some support to these views is lent by the known chelation of alkali metals with salicylaldehyde (see, *e.g.*, Sidgwick and Brewer, *J.*, 1925, 2379), and some evidence to support a partially covalently bound metal atom is given by the observation that sodium 2-pyridyl oxide (m. p. 354—357°) and potassium 2-quinolyl oxide (m. p. 325°) both melt to clear orange-brown liquids, and both are soluble in hot anhydrous pyridine; they are however insoluble in boiling xylene.

The difficulty of carboxylating hydroxy-pyridines and -quinolines in the heterocyclic nucleus by the Kolbe–Schmitt reaction is reflected in the very few references in the elitrature. Tschitschibabin and Kirssanow (*Ber.*, 1924, **57**, 1161) reported that carboxylation of sodium 2-quinolyl oxide did not occur under the normal Kolbe–Schmitt reaction conditions. However, because potassium 6-quinolyl oxide is more reactive towards carbon dioxide than the sodium compound (Schmitt and Altschul, *Ber.*, 1887, **20**, 2695) we have attempted to carboxylate potassium 2-quinolyl oxide under a variety of conditions but without success (see Experimental section). A chelated structure, such as (XII), particularly at elevated temperatures, and the consequent reduced mobility of the metal, would explain the much greater difficulty of carboxylating such metal compounds (cf. Hales, Jones, and Lindsey, *J.*, 1954, 3145); and in the case of sodium 2-pyridyl oxide the preferred carboxylation at the 5-position (Tschitschibabin and Kirssanow, *loc. cit.*; Baine, Adamson, J. W. Barton, Fitch, Swayampati, and Jeskey, *J. Org. Chem.*, 1954, **19**, 510). Similarly, for potassium 2-quinolyl oxide (XIII) the much reduced activity at position 3 and the blocking of position 5 prevent ready carboxylation. A similar inertness towards the Kolbe–Schmitt reaction has been reported for tropolone (Cook, Raphael, and Scott, *J.*, 1952, 4416) and here again it is probable that a chelated structure (XIV) prevents carboxylation. In the case of 3-hydroxypyridine intramolecular chelation cannot readily occur and good yields of both 2- and 6-carboxylic acids have been reported (Bojarska-Dahlig and Urbanski, *Roczniki Chem.*, 1952, **26**, 158; Jeskey *et al.*, *loc. cit.*).

Experimental

Microanalyses were carried out by Miss Corner and her staff of this Laboratory.

Infrared Absorption Spectra.—Spectra were measured on a modified Hilger D209 double-beam instrument (Hales, *J. Sci. Instr.*, 1949, **26**, 359; 1953, **30**, 52). Solid compounds were examined in potassium chloride discs (Hales and Kynaston, *loc. cit.*) and as mulls in Nujol. Mulls of hygroscopic materials were prepared in a dry box.

Ultraviolet Absorption Spectra.—These were measured for ethyl alcohol solution on a Unicam S.P. 500 Spectrophotometer.

Materials.—2-Pyridone, purified by repeated sublimation, had m. p. 106° (Found: C, 63·1;

H, 5·15; N, 13·9. Calc. for C_5H_5ON: C, 63·2; H, 5·3; N, 14·7%), $\lambda_{max.}$ 227·5, 299·0 mμ (log ε 3·90, 3·72).

3-Hydroxypyridine, purified by sublimation, had m. p. 125° (Found: C, 63·2; H, 5·4; N, 15·05. Calc. for C_5H_5ON: C, 63·2; H, 5·3; N, 14·7%), $\lambda_{max.}$ 218·0, 280·0 mμ (log ε 3·84, 3·68).

6-Methyl-2-pyridone, prepared by dehydrogenation of 6-methyl-2-piperidone over palladium black (Jones and Lindsey, *J.*, 1952, 3261) and purified by sublimation, had m. p. 159—160°.

2-Quinolone, purified by sublimation, had m. p. 200·5—201° (Found: C, 74·6; H, 5·1; N, 9·7. Calc. for C_9H_7ON: C, 74·5; H, 4·8; N, 9·8%), $\lambda_{max.}$ 230·0, 268·0 mμ (log ε 4·55, 3·82).

4-Methyl-2-quinolone, purified by sublimation, had m. p. 229—230° (Found: C, 75·6; H, 5·8; N, 8·8. Calc. for $C_{10}H_9ON$: C, 75·5; H, 5·9; N, 8·8%), $\lambda_{max.}$ 230·0, 268·0 mμ (log ε 4·57, 3·80).

Sodium 2-pyridyl oxide. 2-Pyridone (500 mg.) in methanol (5 ml.) was added to sodium hydroxide (210 mg.) dissolved in methanol (10 ml.). The methanol was removed under reduced pressure and the sodium 2-pyridyl oxide, as a white powder, was dried *in vacuo* at 130°; it had m. p. 345—347° (sealed tube) (Found: Na, 19·7. Calc. for C_5H_4ONNa: Na, 19·5%) and was readily soluble in anhydrous pyridine but insoluble in boiling anhydrous ether, toluene, or xylene.

Potassium 2-quinolyl oxide. This oxide, prepared as above and dried *in vacuo* at 160°, had m. p. 325° to an orange liquid (sealed tube) (Found: K, 21·9. Calc. for C_9H_6ONK: K, 21·3%). Potassium 2-quinolyl oxide was easily soluble in anhydrous pyridine but insoluble in boiling anhydrous xylene.

Attempted Carboxylation of Potassium 2-Quinolyl Oxide.—Potassium 2-quinolyl oxide was heated (i) at 214°/30 atm. (CO_2) for 3 hr., (ii) with anhydrous potassium carbonate, at 250°/36 atm. (CO_2), or in anhydrous pyridine at 200°/130—140 atm. (CO_2) for 6 hr. and 2-quinolone and anhydrous potassium carbonate were heated at 200—250°/60 atm. (CO_2) for 5 hr. No carboxylation occurred.

Infrared Spectra.—Absorption centres are given in cm.$^{-1}$; w = weak; m = medium; s = strong; sh = shoulder; bb = broad band. Nujol and solvent bands have been omitted.

2-Pyridone. (i) In KCl disc: 3060 m, *ca.* 2980 s, 1670 s, 1645 s, 1600 s, 1571 s, 1532 s, 1451 m, 1428 m, 1413 m, 1357 w, 1239 s, 1171 w, 1155 s, 1130 sh, 1097 s, 1008 m, 982 s, 962 sh, 926 m, 865 w, 845 w, 835 w, 781 s, 731 m. (ii) In Nujol: 3100 m, *ca.* 2925 s, 1680 sh, 1647 s, 1607 m, 1577 s, 1544 sh, 1435 s, 1368 sh, 1244 s, 1174 w, 1158 s, 1132 sh, 1098 s, 1008 m, 984 s, 962 sh, 926 m, 901 sh, 865 w, 846 w, 835 w, 782 s, 731 m. (iii) In carbon tetrachloride (dilute solution): 3250 w, 3100 m, 2930 s, 2800 s, 1835 w, 1679 sh, 1658 s, 1618 s, 1473 m, 1437 m, 1372 w, 1248 s, 1152 m, 1096 m, 992 s, 924 m, 846 m. (iv) In chloroform (dilute solution): 3350 w, 3250 w, 3100 m, 2800 s, 1672 sh, 1650 s, 1608 s, 1540 s, 1470 s, 1438 s, 1370 w, 1252 s, 1155 m, 1097 m, 1055 w, 993 s, 926 m, 849 m.

3-Hydroxypyridine. (i) In KCl disc: 2875 m, *ca.* 2430 s. bb, *ca.* 1780 s. bb, 1600 w, 1560 s, 1471 s, 1366 s, 1305 m, 1285 sh, 1274 s, 1236 s, 1209 sh, 1179 m, 1121 w, 1099 m, 1048 m, 1020 m, 926 w, 914 w, 905 w, 895 m, 848 m, 842 sh, 823 w, 806 s, 800 s, 703 s. (ii) In Nujol: *ca.* 2430 s, bb, *ca.* 1780 s, bb, 1600 w, 1563 s, 1458 s, 1368 s, 1309 m, 1287 sh, 1277 s, 1236 s, 1209 sh, 1178 m, 1121 w, 1098 m, 1046 m, 1019 m, 977 w, 914 w, 905 w, 894 m, 843 m, 828 m, 807 s, 800 s, 703 s. (iii) In chloroform (saturated solution): 1580 w, 1279 m, 1099 w, 1050 w.

6-Methyl-2-pyridone. (i) In Nujol: 3100 m, 1676 s, 1657 sh, 1612 s, 1548 m, 1208 w, 1166 m, 998 m, 939 m, 927 m, 812 w, 800 m, 736 w. (ii) In chloroform (dilute solution): 3350 sh, 3280 m, 3100 sh, 2800 s, 1965 w, 1858 w, 1776 w, 1650 s, 1622 sh, 1552 s, 1466 s, 1450 s, 1400 s, 1374 sh, 1160 s, 1034 m, 998 s.

2-Quinolone. (i) In KCl disc: 3060 m, 2970 m, 2825 m, 1654 sh, 1638 s, 1595 s, 1547 m, 1498 m, 1466 m, 1422 s, 1390 m, 1343 m, 1305 w, 1279 m, 1256 m, 1206 m, 1151 m, 1132 m, 1116 m, 1026 m, 981 w, 945 m, 923 w, 900 w, 864 m, 834 s, 774 m, 761 s, 831 m. (ii) In Nujol: 3100 sh, 1635 s, 1593 s, 1552 m, 1500 m, 1463 m, 1425 s, 1395 m, 1345 m, 1307 m, 1305 w, 1279 m, 1258 m, 1207 m, 1151 m, 1132 m, 1116 m, 1026 m, 981 w, 945 m, 924 w, 900 w, 864 m, 834 s, 774 m, 761 s, 831 m. (iii) In carbon tetrachloride (saturated solution; very insoluble): 1660 s. (iv) In chloroform (sat. solution): 3350 w, 2820 s, 1660 s, 1605 s, 1553 m, 1422 s, 1342 w, 1279 m, 1261 m, 1152 m, 1138 m, 1120 m, 1028 m, 979 w, 943 m, 861 m, 831 s.

4-Methyl-2-quinolone. (i) In KCl disc: 3075 w, 2930 s, 2780 s, 1795 w, 1644 s, 1600 sh, 1545 m, 1500 m, 1425 s, 1383 m, 1364 m, 1342 w, 1258 w, 1203 w, 1157 w, 1140 w, 1070 w, 1031 w, 963 m, 929 m, 884 m, 864 m, 852 m, 767 w, 755 s, 746 s, 702 w, 663 m. (ii) In Nujol: 3100 sh, 2870 sh, 2720 sh, 1795 w, 1645 s, 1604 sh, 1554 m, 1506 m, 1430 s, 1390 m, 1369 m, 1350 w, 1261 w, 1205 w, 1160 w, 1143 w, 1071 w, 1034 w, 964 m, 931 m, 884 m, 864 m, 853 m, 765 w,

755 s, 745 s, 700 w, 663 m. (iii) In chloroform (saturated solution): 3330 w, 2825 s, 1653 s, 1605 m, 1548 m, 1425 s, 1391 m, 1372 sh, 1342 w, 1261 m, 1070 w, 1033 w, 965 w, 945 w, 890 w, 870 m.

Sodium 2-pyridyl oxide. In Nujol: 1600 s, 1532 w, 1480 s, 1440 s, 1424 sh, 1353 s, 1283 m, 1228 w, 1194 w, 1143 m, 1095 w, 1035 w, 984 s, 955 w, 862 sh, 855 s, 832 w, 790 s, 737 s.

Potassium 2-quinolyl oxide. In Nujol: 3020 w, bb, 1605 s, 1542 s, 1498 s, 1424 s, 1302 m, 1288 m, 1256 m, 1243 sh, 1205 w, 1139 m, 1116 m, 1020 w, 964 w, 936 w, 922 w, 905 w, 864 w, 828 s, 796 w, 771 w, 758 s, 751 s, 731 m, 695 w.

We thank Dr. J. Idris Jones and Mr. J. L. Hales for helpful discussions and one of us (J. A. G.) thanks D.S.I.R. for a vacation studentship. This paper is published by permission of the Director of the Chemical Research Laboratory.

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Interaction between Acrylonitrile and Amorphous Carbons.

By M. C. R. SYMONS.

[Reprint Order No. 6618.]

Degassed sugar-chars and certain carbonized coals have been found to cause slight polymerisation of acrylonitrile at 60°. Carbon "activated" by being heated in moist air does not initiate polymerisation in the dark, and inhibits photopolymerisation unless traces of oxygen are present, whereupon a photosensitive material is formed, and extensive polymerisation occurs. These results are related to the paramagnetic resonance absorption of the carbons.

CERTAIN forms of amorphous carbon and coal are paramagnetic (Bennet and Ingram, *Phil. Mag.*, 1954, **45**, 545; Ingram and Tapley, *ibid.*, p. 1221; Ingram, Tapley, Jackson, Bond, and Murnaghan, *Nature*, 1954, **174**, 797; Garten and Weiss, *Austral. J. Chem.*, 1955, **8**, 68). It is well known that free radicals are paramagnetic, and that sufficiently reactive radicals, formed in the presence of certain vinyl monomers, will initiate polymerisation. The object of this work was to discover whether carbon surfaces initiate polymerisation and, if so, under what conditions.

Few studies of catalysis of polymerisation of vinyl compounds by solids have been reported. Paravano (*J. Amer. Chem. Soc.*, 1950, **72**, 3856, 5546) found that some surfaces, including carbon, while not themselves capable of initiating polymerisation, can indirectly catalyse the polymerisation of aqueous methyl methacrylate when certain reactions are proceeding on the surface. Unfortunately the nature of the carbon used in these experiments was not stated. He postulated that polymerisation was initiated by active radical intermediates which occasionally escaped from the surface. Markham and Laidler (*J. Phys. Chem.*, 1953, **57**, 363) found that aqueous suspensions of zinc oxide irradiated with ultraviolet light (largely 3650 Å) could initiate the polymerisation of methyl methacrylate and acrylonitrile. No polymerisation occurred in the absence of zinc oxide. However, a short induction period was observed, and these authors suggest that, despite careful precautions, some oxygen may have been present. They postulate that, as a consequence of light absorption, an electron is transferred from the catalyst to a water molecule, with consequent formation of a hydrogen atom. It seems, however, that the significance of these results is limited since, if oxygen was present, some hydrogen peroxide would have been formed and its photolysis could have initiated the polymerisation.

One instance when radicals present in the solid phase initiate polymerisation is described by Bamford and Jenkins (*Proc. Roy. Soc.*, 1953, *A*, **216**, 515; 1955, *A*, **228**, 220), who found that coagulated solid polymer formed during the photo-polymerisation of pure acrylonitrile at room temperature could initiate further polymerisation, in the dark, on being warmed to 60°. These, and other results (Bamford and Barb, *Discuss. Faraday Soc.*, 1953, **14**, 208), led them to postulate that growing polymer radicals had become trapped in the coagulated

polymer in such a way that monomer could only diffuse to the radicals at an elevated temperature. This catalysis was suppressed when oxygen was admitted to the system. In agreement with this theory, a small but definite paramagnetic resonance absorption has been observed in a specimen of polyacrylonitrile formed in this manner (Bamford, Jenkins, Ingram, and Symons, *Nature*, **1955**, **175**, 894).

Experimental

Materials.—Sugar char, designated "C_s," was prepared by carefully heating "AnalaR" sucrose in an all-glass system *in vacuo* to 400° until a pressure of 10^{-4} mm. could be maintained. In some experiments the resulting char was cooled and ground to a fine powder before use, in others the specimen was used directly without exposure to oxygen. The results were qualitatively the same with either procedure. Two samples of sugar char, both referred to as C_a, were activated at 400° and 550° respectively in a stream of moist air for 13 hr. (Garten and Weiss, *loc. cit.*). Two coal specimens, C_c, were carbonized at 510° and 520° respectively in nitrogen for 45 min. Acrylonitrile was purified by being shaken with dilute sulphuric acid, dilute sodium hydroxide, and purified water, dried ($CaCl_2$), and de-aerated by repeated distillation *in vacuo* into tubes cooled in liquid oxygen. Water was distilled from, and glass-ware was cleaned with, alkaline permanganate. *In vacuo* refers to a pressure between 10^{-4} and 10^{-5} mm.

Procedure.—The carbon (*ca.* 0·1 g.) in a Pyrex tube ($\frac{1}{4}$ in. diameter) was gradually heated to 400° *in vacuo* until evolution of gas ceased. After immersion of the tube in liquid oxygen, pure de-aerated acrylonitrile was allowed to pass into it so that, on melting, there was a $\frac{1}{2}$ in. layer of momomer above the carbon. The mixtures were shaded from direct sunlight, since, under certain conditions, ultraviolet light was found to catalyse the initiation of polymerisation. There was no apparent change after 24 hr. at room temperature, but with C_s and C_c, on warming to 60°, a cloudy suspension of polymer grew from the surface of the carbon, and within a few minutes had spread vertically through the monomer. Sometimes a small flocculent precipitate settled on the carbon surface before polymerisation ceased. A rough estimate based on the turbidity gives the overall conversion into polymer as 0·1%. The whole of the reaction tube, including the upper part filled with vapour, was warmed to 60° : if only the liquid was warmed some boiling occurred with agitation of the liquid. Under these conditions no polymer was seen, probably because it adhered to the rapidly moving carbon particles. Paravano (*loc. cit.*) also found that the liquid must be stationary for polymerisation to be observed. In the dark, a trace of oxygen prevented polymerisation.

In other experiments the acrylonitrile–carbon mixtures were irradiated at room temperature with ultraviolet light filtered through Pyrex glass from a medium-pressure 250-w mercury arc 9 in. from the specimen. Under these conditions pure acrylonitrile, in the absence of carbon, polymerised very slowly, and was used as a control. This natural rate of polymerisation was not altered by C_s or C_c, but the "activated" steam-treated carbons acted as inhibitors and no turbidity could be seen after 12 hr. However, a slight yellow colour was then apparent, and filtration and vacuum-distillation yielded a trace of high-boiling oil which was probably a polymer of low molecular weight, soluble in the monomer.

When irradiated mixtures were freely and continuously exposed to air, no polymerisation occurred. If, after exposure to air, and before irradiation, the mixtures were throughly degassed by repeated freezing *in vacuo*, irradiation produced rapid and extensive polymerisation, which was shown to be due to a soluble, photosensitive substance, since rapid polymerisation occurred in the liquid after decantation from the carbon. For results see Table.

Polymerisation of acrylonitrile in presence of carbons.

	Oxygen-free * in dark, 60°		Irradiated, 20° Time to first turbidity and subsequent rate	
Carbon	Time to first turbidity	Approx. % polymer at completion	Oxygen-free	In presence of trace * of oxygen
C_s	Immediate	0·1%	5 min., slow	1 min., rapid
C_c	Immediate	0·1%	5 min., slow	1 min., rapid
C_a	No polymerisation		No polymerisation	2 min., rapid
Nil	No polymerisation		5 min., slow	5 min., slow

* With *free* exposure to air no polymerisation occurred on any of the carbons.

In an attempt to discover what soluble, photosensitive material can be liberated from oxygenated carbon, the ultraviolet absorption spectra of aqueous extracts from various carbons

were examined with a Unicam SP 500 quartz spectrophotometer. The water was de-aerated by repeated partial freezing and distillation *in vacuo*, and distilled on to the de-aerated carbon prepared as above. The extract from carbons which had never been exposed to oxygen had an absorption spectrum identical with that of water. When oxygen had been admitted before filtering off the carbon the absorption was generally similar to that of a dilute solution of hydrogen peroxide, except that absorption was rather stronger from 200 to 220 mμ. Since it was thought likely that traces of oxalic acid were present (King, *J.*, 1933, 842; 1934, 22) attempts were made to reproduce the curve obtained from the extract by mixing hydrogen peroxide with oxalic acid. It was ultimately found that a solution 10^{-4}M in hydrogen peroxide and $1{\cdot}2 \times 10^{-4}$M in oxalic acid gave a curve almost identical with that obtained from the carbon extract in the 200—300 mμ region. The extracts from different forms of carbon had substantially the same ultraviolet absorption. The inference that hydrogen peroxide and oxalic acid were present was supported by the following tests made on the aqueous extracts: Cold acidified potassium permanganate solution was immediately decolorised, a blue colour at once appeared in a starch–iodide solution, and a faint but definite precipitate was obtained from a calcium chloride solution. Various spot-tests for formic acid were inconclusive.

For measurement of paramagnetic resonance absorption the monomer was removed by distillation *in vacuo*, and the tube with the carbon placed in an H_{012} 3 cm.-wavelength rectangular resonant cavity at room temperature. All the carbons retained a strong absorption, showing that only a small percentage of the radical centres had beeen involved in the polymerisation. The intensity of the signal was always less than that of the original carbons, but quantitative interpretation of the measurements is not practicable since the strength of the signal depends on the concentration of the carbon, which had been altered through aggregation of the particles, and may also be affected by acrylonitrile polymer adhering to the carbon.

The effect of admitting air to the carbon, before and after treatment with acrylonitrile, was also observed. On admission of air to a carbon not previously in contact with acrylonitrile the strength of the signal decreased suddenly (Ingram and Tapley, *Chem. and Ind.*, 1955, 568). The percentage decrease varied with the nature of the carbon and its previous treatment but was always more than 50%. When air was admitted to a carbon previously treated with acrylonitrile, the signal very slowly decreased by not more than 5%. The inference is that the pores of the carbon are clogged with acrylonitrile, preventing the adsorption of oxygen.

Discussion

The fact that oxygen-free carbons initiate polymerisation in the dark shows that active free radicals must be present in the carbon. This polymerisation does not extend visibly into the liquid below about 60°; at room temperature no more than a slightly increased tendency of the carbon particles to adhere is observed. Probably polymerisation proceeds in the pores of the carbon at room temperature but cannot easily continue out into the liquid until the temperature is high enough for molecules of monomer to penetrate the polymer and reach the free radicals in the pores.

All the chars consist of multinuclear aromatic ring systems (Riley, *Quart. Rev.*, 1947, **1**, 59). The radicals probably present may be divided into two classes: first, stable, benzyl-type radicals in which the orbital of the single electron can overlap efficiently with the π-orbitals of the ring system to which the carbon carrying the single electron is attached; such radicals would probably be ineffective as initiators of polymerisation and might well act as inhibitors (Burnett, " Mechanism of Polymer Reactions," Interscience Publishers Ltd., 1954, p. 84). Secondly, reactive phenyl-type radicals in which the unpaired electron is localised on one carbon atom might well remain in the rigid network if pyrolysis proceeds by homolysis of bonds. Ingram *et al.* (*locc. cit.*) estimate that the ratio of carbon atoms to unpaired electrons in coals and carbons similar to those used here is about 1600, but it is probable that many active centres are in positions inaccessible to the monomer or other adsorbates.

Garten and Weiss (*loc. cit.*) suggest that the paramagnetism of amorphous carbons arises because some of the multinuclear ring systems have a slightly semiquinone character. The presence of oxygen is however not necessary for paramagnetic resonance, since Bennett, Ingram, and Tapley (*J. Chem. Phys.*, 1955, **23**, 215) found that chars obtained *in vacuo* from hydrocarbons have the same distinctive paramagnetic properties. They have also stressed

that the small paramagnetic resonance found in graphite (Castle, *Phys. Rev.*, **1953**, **92**, 1063; **1954**, **94**, 1410) has quite different characteristics from that of amorphous carbons. It therefore seems likely that slight unparing of the π-electrons in large multinuclear structures makes little contribution to the paramagnetism observed in amorphous carbons.

The fact that " activation " by treatment with moist air destroys the power of initiating polymerisation in the dark, and also prevents photopolymerisation, may be due to the presence of phenolic groups on the carbon. Garten and Weiss (*loc. cit.*) give evidence that such " activated " carbons contain a number of phenolic hydroxyl and quinone groups.

The formation of oxalic acid when carbon is treated with water and oxygen was previously observed by King (*J.*, **1933**, 842; **1934**, 22). Among others, Garten and Weiss (*loc. cit.*) have postulated the formation of hydrogen peroxide, for which evidence is given here, but the mechanism of its formation is still obscure. It might possibly arise from reaction of molecular oxygen with hydrogen attached to the carbon. An alternative possibility is the reversible formation of the radical ⋮C·O·O·, as postulated by Bamford, Jenkins, Ingram, and Symons (*Nature*, **1955**, **175**, 894) for the first stage of the interaction between oxygen and acrylonitrile radicals. This could subsequently react with water or mobile organic molecules to give a peroxide. Possibly the quenching effect of oxygen on the paramagnetic signal is due to the formation of this or a similar radical on the carbon surface. The superoxide radical ion O_2^- has a very broad paramagnetic absorption band (Bennett, Ingram, Symons, George, and Griffith, *Phil. Mag.*, 1955, **46**, 443): if the ⋮C·O·O· radical has a similar broad absorption band this would account for the quenching of the narrow band found with oxygen-free carbon.

Thanks are offered to Dr. D. J. E. Ingram and Mr. J. G. Tapley for making the paramagnetic-resonance measurements and for helpful discussions, and to Dr. C. H. Bamford and Professor N. K. Adam, F.R.S., for continued encouragement and advice.

THE UNIVERSITY, SOUTHAMPTON. [*Received, July 15th*, 1955.]

Reactions in the Diene Series: Condensation of Isoprene with Aniline and Phenol.

By G. R. CLEMO and N. D. GHATGE.

[Reprint Order No. 6690.]

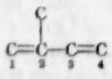
Condensation of isoprene with aniline gives 1 : 2 : 3 : 4-tetrahydro-2 : 2- and -4 : 4-dimethylquinoline, with a third, unidentified, base. After reaction with phenol only 2 : 2-dimethylchroman was identified.

ISOPRENE and aniline (1 mol. each), with a trace of iodine at 150—160°, give a mixture of basic and non-basic products. From the former by fractionation and picrate formation two isomeric secondary bases have been separated which gave quinaldine and lepidine respectively, after dehydrogenation. That the former (formed in much the greater amount is 1 : 2 : 3 : 4-tetrahydro-2 : 2-dimethylquinoline (II) is shown by its conversion into 1 : 2 : 3 : 4-tetrahydro-1 : 2 : 2-trimethylquinoline (Freund and Richard, *Ber.*, **1909**, **42**, 1112). The other secondary base is doubtless 1 : 2 : 3 : 4-tetrahydro-4 : 4-dimethylquinoline. It too has been methylated but 1 : 2 : 3 : 4-tetrahydro-1 : 4 : 4-trimethylquinoline does not appear to have been described previously. Thus aniline condenses in the two possible ways, with $C_{(2)}$ and $C_{(4)}$ of isoprene [see (I)].

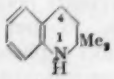
A third, isomeric base was separated as a greenish picrate in insufficient amount for further investigation. The colour of the picrate, however, appears to show that condensation has not taken place on $C_{(1)}$ and $C_{(3)}$ of isoprene to give a reduced quinoline, but rather at positions 1 : 2 or 3 : 4, to give a dihydroindole, or possibly at positions 1 : 4 to give a reduced seven-membered ring base.

Claisen (*Ber.*, 1921, **54**, 200) reported that condensing isoprene with phenol yields 2 : 2-dimethylchroman (III). We have repeated this and also isolated the chroman (III), the

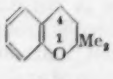
structure of which is proved by its dehydrogenation to 6 : 6-dimethyl-1 : 2-benzopyran which on ozonolysis gives salicylaldehyde (Shriner and Sharp, *J. Org. Chem.*, 1939, **4**, 575). In the condensation of but-2-enyl bromide and trimethylquinol Karrer (*Helv. Chim. Acta*, 1939, **22**, 1287) obtained a chroman–coumaran mixture but so far no coumaran has been isolated from the reaction of isoprene with phenol.



(I)



(II)



(III)

In efforts to open the ether ring of the chroman (III) by acid we were unsuccessful, but treatment with acetic anhydride and zinc chloride gave a ketone and an acid. The former suggested a Friedel–Crafts acylation to give a 6- or 8-acetyl derivative of the chroman (III), and the properties of the acid suggests the introduction of the $-CH_2 \cdot CO_2H$ group into the chroman. To settle the structure of the ketone condensation of *o*- and *p*-hydroxyacetophenone with isoprene was examined. In the former case only a trace of cyclic product was obtained, but in the latter a crystalline product resulted which differed from the ketone described above. Further the Willgerodt reaction on 6-acetyl-2 : 2-dimethylchroman gave a crystalline acid different from that obtained in the zinc chloride–acetic anhydride reaction which appears, therefore, to be the 8-acetyl derivative.

Experimental

Condensation of Isoprene with Aniline.—Isoprene (5 g.), aniline (7 g.), and a crystal of iodine were heated at 150—160° in a sealed tube for 8 hr. Extraction of the mixture with hydrochloric acid and subsequent basification and fractionation (2 mm.) gave fractions : (2 g.) b. p. 40—54°; (0·2 g.) b. p. 54—90°; (1·5 g.) b. p. 92—100°; (1·5 g.) thick viscous product b. p. up to 170°; residue (1·2 g.). The first fraction was recovered aniline. The third fraction (1 g.) in ether was added to ethereal picric acid (1·5 g.); after ½ hr. the picrate (*A*) was collected and dried (1·6 g.), and the mother-liquor concentrated; yellow crystals (*B*) (0·2 g.) separated overnight. The mother-liquors from two such experiments were further concentrated and left for 24 hr.; green prisms (*C*) separated, with more of the picrate (*B*).

Picrate (A) was recrystallised from alcohol, giving prisms, m. p. 152° (Found : C, 52·3; H, 4·7. $C_{17}H_{18}O_7N_4$ requires C, 52·3; H, 4·6%). Treatment with ammonia gave 1 : 2 : 3 : 4-*tetrahydro*-2 : 2-*dimethylquinoline*, b. p. 95—98°/2 mm. (Found : C, 81·6; H, 9·5. $C_{11}H_{15}N$ requires C, 81·9; H, 9·3%). With nitrous acid it formed a *nitronitroso-derivative*, m. p. 159° (Found : C, 55·8; H, 5·7. $C_{11}H_{13}O_3N_3$ requires C, 56·2; H, 5·5%). On dehydrogenation with selenium at 300° a base was obtained whose picrate melted at 194—195° alone or mixed with quinaldine picrate (Found : C, 51·8; H, 3·5. Calc. for $C_{16}H_{12}O_7N_4$: C, 51·6; H, 3·2%).

The base (0·2 g.) from picrate (*A*) was heated at 100° for 12 hr. with methyl iodide (1·5 c.c.). On cooling, 1 : 2 : 3 : 4-*tetrahydro*-1 : 2 : 2-*trimethylquinoline hydriodide* separated. This recrystallised from alcohol ether as prisms, m. p. 167° (Found : C, 48·1; H, 6·3. $C_{12}H_{17}N,HI$ requires C, 47·5; H, 6·0%). When this was heated with potassium hydroxide a base distilled which gave a picrate, m. p. 178—179° (lit., m. p. 178°) (Found : C, 53·6; H, 5·3. Calc. for $C_{18}H_{20}O_7N_4$: C, 53·5; H, 4·9%).

Picrate (B) formed yellow prisms, m. p. 115° (Found : C, 52·6; H, 4·9%), and treatment with ammonia liberated a base, b. p. 98°/2 mm. (Found : C, 82·3; H, 9·5%), which gave the Liebermann reaction. On dehydrogenation with selenium a base was obtained whose picrate melted at 212—213° alone or mixed with lepidine picrate (Found : C, 51·8; H, 3·5%). 1 : 2 : 3 : 4-Tetrahydro-1 : 4 : 4-trimethylquinoline was formed *via* the *hydriodide*, plates, m. p. 243—244° (Found : C, 48·1; H, 6·4%), and gave a *picrate*, m. p. 165° (Found : C, 53·2; H, 4·7%).

Picrate (C) formed greenish needles (from methanol), m. p. 165° (Found : C, 52·1; H, 4·6%).

Condensation of Isoprene with Phenol.—Isoprene (1 mol.), phenol (1 mol.), and a trace of iodine were heated in a sealed tube. The best yield (15%) of neutral steam-distilled product was obtained at 150°. This was fractionated; 24% of the product distilled at 82—92°/2 mm., showed no unsaturation, and was analysed as 2 : 2-dimethylchroman (Found : C, 81·6; H, 8·9. Calc. for $C_{11}H_{14}O$: C, 81·5; H, 8·6%).

The chroman (3·5 g.), *N*-bromosuccinimide (4·1 g.), and benzoyl peroxide (0·17 g.) were

refluxed in carbon tetrachloride (15 c.c.) with stirring for 4 hr. The cold mixture was filtered, the solvent removed, and the residue heated in benzene (20 c.c.) with sodium ethoxide on the water-bath for 3 hr. After addition of water the benzene layer was separated and distilled, giving a fraction, b. p. 76—80°/2 mm., n_D^{20} 1·546 (lit., b. p. 79—80°/2 mm., n_D^{20} 1·549). Ozonolysis gave salicylaldehyde whose 2 : 4-dinitrophenylhydrazone had m. p. and mixed m. p. 252°.

Action of Acetic Anhydride and Zinc Chloride on the Chroman (III).—2 : 2-Dimethylchroman (0·6 g.), acetic anhydride (15 c.c.), and zinc chloride (1 g.) were heated in a sealed tube in the water-bath for 12 hr. The excess of anhydride was decomposed by water, the mixture extracted with ether, the ether removed, and the residue distilled at 180—190°/0·1 mm. to give a solid. This was separated by sodium hydrogen carbonate solution to give a *ketone*, needles, m. p. 75° (from light petroleum) (Found : 76·3; H, 8·2. $C_{13}H_{16}O_2$ requires C, 76·5; H, 7·8%), and an *acid*, prisms, m. p. 181—182° (from light petroleum) (Found : C, 70·5; H, 7·5. $C_{13}H_{16}O_3$ requires C, 70·9; H, 7·3%). The ketone gives a 2 : 4-*dinitrophenylhydrazone*, m. p. 255°, and the acid a *methyl ester*, m. p. 87° (Found : C, 71·5; H, 7·8%; *M*, 225. $C_{14}H_{18}O_3$ requires C, 71·8; H, 7·7%; *M*, 234).

6-*Acetyl*-2 : 2-*dimethylchroman*.—Isoprene (3 g.), *p*-hydroxyacetophenone (3·2 g.), and a crystal of iodine were heated at 150° for 6 hr. The mixture was made alkaline and steam-distilled. The distillate solidified and gave the 6-*acetyl derivative* as prisms, m. p. 90° (1·2 g.), from light petroleum (Found : C, 76·8; H, 8·2. $C_{13}H_{16}O_3$ requires C, 76·5; H, 7·8%). It forms a 2 : 4-*dinitrophenylhydrazone*, m. p. 244° (Found : C, 59·6; H, 5·5. $C_{19}H_{20}O_8N_4$ requires C, 59·4; H, 5·2%).

Willgerodt Reaction on 6-*Acetyl*-2 : 2-*dimethylchroman*.—The chroman (0·13 g.), sulphur (0·18 g.), pyridine (0·4 c.c.), and ammonia solution (0·3 c.c. ; *d* 0·88) were heated at 120° for 5 hr. The dried product was refluxed for 4 hr. with 10% aqueous sodium hydroxide (5 c.c.), then diluted and filtered and the filtrate acidified with hydrochloric acid. The resulting *acid* formed prisms, m. p. 165° (50 mg.), from light petroleum, depressed on admixture with the acid of m. p. 181—182° (Found : C, 70·5; H, 7·2. $C_{13}H_{16}O_3$ requires C, 70·9; H, 7·3%).

KING'S COLLEGE, NEWCASTLE UPON TYNE, 1. [*Received, August 15th*, 1955.]

New Ring Systems of Potential Carcinogenic Activity. Part I. Derivatives of 4 : 9 : 10-*Triaza*-1 : 2-5 : 6- *and* -1 : 2-7 : 8-*dibenzanthracene.*

By T. S. OSDENE and G. M. TIMMIS.

[Reprint Order No. 6145.]

The unambiguous synthesis of 4 : 9 : 10-triaza-1 : 2-7 : 8- and -1 : 2-5 : 6-dibenzanthracene and 3-substituted derivatives thereof is reported. The 3-hydroxy- and 3-amino-derivatives in these series were synthesised from 1-nitroso-2- and 2-nitroso-1-naphthylamine by condensation with 2-methoxycarbonylbenzyl cyanide and 2-cyanobenzyl cyanide in the presence of sodium ethoxide. A double ring-closure occurred, the hydroxy- and amino-substituents being derived from the *o*-methoxycarbonyl and *o*-cyano-moieties respectively of the substituted benzyl cyanides.

SINCE inhibition of growth of experimental tumours may be brought about by the administration of carcinogenic polycyclic hydrocarbons (Haddow, *J. Path. Bact.*, 1938, **47**, 467) and nitrogen-containing heterocycles (Badger, Elson, Haddow, Hewett, and Robinson, *Proc. Roy. Soc.*, 1942, *B*, **130**, 255) of similar complexity and skeletal shape, the synthesis of new heterocycles of this type is of interest because their properties may confirm or provide exceptions to the apparent rule that carcinogenic and tumour-inhibiting properties are associated.

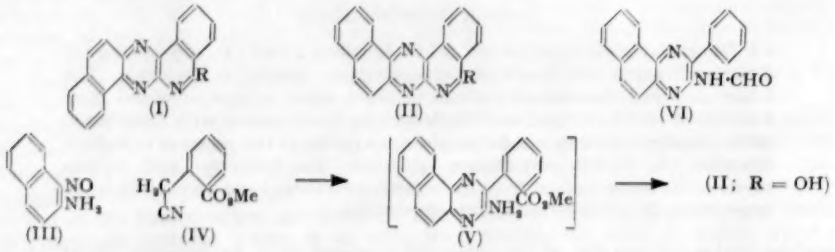
In a structurally very dissimilar case a series of acylaziridines has been found by Walpole, Roberts, Rose, Hendry, and Homer (*Brit. J. Pharmacol.*, 1954, **9**, 316) to be carcinogenic but not tumour-inhibitory. Also, new aza-analogues of the carcinogenic hydrocarbons extend the range of polycyclic structures which are being studied theoretically by Pullman

[*Ann. Chim.* (*France*), 1947, **2**, 5; *Acta Int. Cancer*, 1948, **6**, 57; *Compt. rend.*, 1953, **236**, 2318, 2508; **237**, 173; *J. Chim. phys.*, 1953, **50**, 548; cf. Pullman, Pullman, and Berthier, *Compt. rend.*, 1953, **236**, 2067] in a search for fundamental causes of carcinogenicity.

These workers claim that an active K region, *e.g.*, the double bond at the 3 : 4- and the 5 : 6-position in 1 : 2-7 : 8-dibenzanthracene, is necessary for carcinogenic activity. 1 : 2-5 : 6- and 1 : 2-7 : 8-Dibenzanthracene are also of interest because they are respectively strong (Shimkin and Wyman, *J. Nat. Cancer Inst.*, 1947, **8**, 49) and weak (Barry, Cook, Haslewood, Hewett, Hieger, and Kennaway, *Proc. Roy. Soc.*, 1935, *B*, **117**, 318) carcinogens, and the former is a tumour inhibitor (Haddow, *loc. cit.*). Activity is retained when carbon in the 9- or 10-position is replaced by one or two nitrogen atoms as in 1 : 2-5 : 6- and 1 : 2-7 : 8-dibenzacridine (Badger, Cook, Hewett, Kennaway, Kennaway, Martin, and Robinson, *Proc. Roy. Soc.*, 1940, *B*, **129**, 439; Haddow, *loc. cit.*) and 1 : 2-5 : 6-dibenzophenazine (Rudali, Chalvet, and Winternitz, *Compt. rend.*, 1955, **240**, 1738). Introducing a third ring-nitrogen atom we have now synthesised new triazadibenzanthracene derivatives in which the carbon–carbon link in the 3 : 4-position has been replaced by an azamethine link. Boyland (*Cancer Res.*, 1952, **12**, 77) has suggested, after a study of many examples, that, in polycyclic carcinogenic hydrocarbons whose structure can be based on that of anthracene two centres of reactivity are necessary for biological activity, *i.e.*, either two K regions or one K region and the *meso*-position of this anthracene moiety. Since in our structures there is one K region and no anthracene nucleus, their investigation for carcinogenicity will show whether Boyland's hypothesis can be strengthened by application to triazadibenzanthracenes.

In a preliminary communication (*Chem. and Ind.*, 1954, 404) we have shown that by condensing 2 : 4-diamino-1-nitrosobenzene with 2-methoxycarbonylbenzyl cyanide a double ring-closure occurred, leading to the formation of 6-amino-3-hydroxy-4 : 9 : 10-triaza-1 : 2-benzanthracene. Analogously it was shown that derivatives of 4 : 9 : 10-triaza-1 : 2-5 : 6- (I) and 1 : 2-7 : 8-dibenzanthracene (II) could be obtained from 2-nitroso-1 and 1-nitroso-2-naphthylamine respectively. The synthesis determines the structure of the product without ambiguity.

When 1-nitroso-2-naphthylamine (III) was treated with 2-methoxycarbonylbenzyl cyanide (IV) in boiling ethanol containing 1 mol. of sodium ethoxide, 3-hydroxy-4 : 9 : 10-triaza-1 : 2-7 : 8-dibenzanthracene (II; R = OH) was precipitated as the sodium salt in good yield. Evidence for the intermediate formation of the amino-ester (V) is contained elsewhere (*J.*, 1955, 2214).

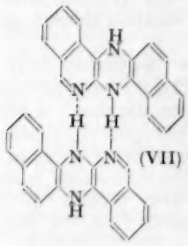


Similarly 2-nitroso-1-naphthylamine and the ester (IV) yielded 3-hydroxy-4 : 9 : 10-triaza-1 : 2-5 : 6-dibenzanthracene (I; R = OH). An attempt to obtain the two parent compounds (I and II; R = H) by replacement of the hydroxy-group in our products by chlorine and subsequent dechlorination, failed in the case of the 1 : 2-7 : 8-dibenzo-series at the replacement stage (treatment with phosphoryl chloride, phosphoryl chloride plus phosphorus pentachloride, or purified thionyl chloride). Replacement by chlorine of the 3-hydroxy-group in the 1 : 2-5 : 6-dibenzo-series was readily achieved with phosphoryl chloride, but attempted dehalogenation of the 3-chloro-derivative (I; R = Cl) with hydrogen in the presence of palladium–charcoal in acetic acid only yielded the phenol (I; R = OH).

As an alternative approach, the 3-hydroxy-derivatives (I and II; R = OH) were converted into thiols by phosphorus pentasulphide in dry pyridine (Klingsberg and Papa, *J. Amer. Chem. Soc.*, **1951**, **73**, 4988), high yields being obtained. 3-Mercapto-4 : 9 : 10-triaza-1 : 2-5 : 6-dibenzanthracene (I; R = SH) was converted into the 3-methylthio-derivative (I; R = SMe) and this with aniline yielded the 3-anilino-compound (I; R = NHPh). Both the thiols (I and II; R = SH) on prolonged heating with aniline yielded the 3-anilino-derivatives (I and II; R = NHPh).

Since the substitution of an amino-group in the 5-position of 1 : 2-benzanthracene appears to confer tumour-inhibitory and possibly carcinogenic activity (Badger *et al.*, *loc. cit.*) an amino-group was introduced into the two heterocycles by treating 1-nitroso-2- and 2-nitroso-1-naphthylamine with 2-cyanobenzyl cyanide under conditions similar to those used for the preparation of the phenols (I and II; R = OH). The 3-amino-derivatives of 4 : 9 : 10-triaza-1 : 2-7 : 8- and -1 : 2-5 : 6-dibenzanthracene (II and I; R = NH_2) were obtained in good yield.

In the preparation of the two parent compounds (I and II; R = H) the 3-mercapto-derivatives were desulphurised with freshly prepared Raney nickel (Brown, *J. Soc. Chem. Ind.*, **1950**, **69**, 355) in 80% aqueous dioxan, to yield orange dihydro-derivatives of the two parent compounds. The solutions of both compounds in butanol showed intense green fluorescences in ultraviolet light. With palladium–charcoal at *ca.* 280° in a high vacuum, they gave the parent compounds (I and II; R = H) as light yellow crystals, which in solution showed intense blue fluorescence in ultraviolet light. We designate the reduced derivatives as dihydro- in preference to the conceivably alternative tetrahydro-compounds mainly on the strength of the analytical figures. This structure enables us to suggest an explanation, which could not apply to the tetrahydro-form, for the orange colour of the dihydro-derivative which in each case, compared with the pale yellow of the parent compound, was surprising. The dihydro-derivative of the 1 : 2-5 : 6-dibenzo-compound (I; R = H) was unaffected by bromine or iodine in hot acetic acid but was easily oxidised by nitrous acid in hot acetic acid to the parent compound (I; R = H) in good yield. These properties suggest that the two hydrogen atoms have been taken up by the pyridoquinoxaline moiety and we suggest speculatively that the orange colour could be attributed to a dimeric structure whose stability depended upon double hydrogen bonding, *e.g.* (VII). Clemo and McIlwain (*J.*, **1935**, 738) observed that the complex formed from phenazine (yellow) and two mols. of diphenylamine (colourless) was orange.


(VII)

Attempted hydrogenation of the compound (I; R = H) in acetic acid with palladium–charcoal failed.

As an alternative synthesis of 4 : 9 : 10-triaza-1 : 2-7 : 8-dibenzanthracene, benzyl cyanide was condensed in ethanol with 1-nitroso-2-naphthylamine in the presence of sodium ethoxide, to yield 2-amino-3-phenyl-5 : 6-benzoquinoxaline but attempts to prepare the *N*-formyl derivative (VI), which it was hoped could by ring-closure yield (II; R = H), failed : formic acid with and without addition of a trace of sulphuric acid, sodium formate, or anhydrous zinc chloride, and also ethyl orthoformate, were used.

Experimental

M. p.s were determined in an electrically heated block. The analyses are by Mr. P. R. W. Baker, Beckenham. " Fluorescence " refers to illumination in ultraviolet light.

2-Amino-3-phenyl-5 : 6-benzoquinoxaline.—To a solution of sodium (0·01 g.) in 2-ethoxyethanol (25 ml.) was added 1-nitroso-2-naphthylamine (1·72 g.) followed by benzyl cyanide (1·3 g.), and the mixture was boiled under reflux for 5 min. The dark brown solution was concentrated at the pump and the residue was triturated with ether. Several crystallisations from ethanol (charcoal) yielded *2-amino-3-phenyl-5 : 6-benzoquinoxaline* as yellow needles, m. p. 193° (Found : C, 79·8; H, 4·9; N, 15·7. $C_{18}H_{13}N_3$ requires C, 79·7; H, 4·8; N, 15·5%).

3-Amino-2-phenyl-5 : 6-benzoquinoxaline.—2-Nitroso-1-naphthylamine (1·72 g.) and benzyl cyanide (1·3 g.) were added to a solution of sodium (0·25 g.) in ethanol (25 ml.), and the mixture was boiled for 1·5 hr. After cooling, the material was collected (1·8 g.). Several crystallisations from ethanol (charcoal) yielded the *5 : 6-benzoquinoxaline* as yellow needles, m. p. 180° (Found: C, 80·0; H, 4·8; N, 15·5%). The ethanol solution showed an intense blue fluorescence.

3-Hydroxy-4 : 9 : 10-triaza-1 : 2-5 : 6-dibenzanthracene (I; R = OH).—2-Nitroso-1-naphthylamine (1·72 g.) and 2-methoxycarbonylbenzyl cyanide (1·9 g.) were added to a solution of sodium (0·25 g.) in dry ethanol (50 ml.), and the mixture was boiled under reflux for 10 min. After cooling, the deposited material was collected and dried (1·8 g.). Several crystallisations from glacial acetic acid yielded the *3-hydroxy*-derivative as pale yellow needles, m. p. 308—309° (Found, on a sample dried *in vacuo* at 150°: C, 76·7; H, 3·9; N, 13·95. $C_{19}H_{11}ON_3$ requires C, 76·75; H, 3·7; N, 14·1%). The acetic acid solution showed an intense yellow fluorescence.

3-Hydroxy-4 : 9 : 10-triaza-1 : 2-7 : 8-dibenzanthracene (II; R = OH).—To a solution of sodium (0·8 g.) in ethanol (100 ml.) were added 1-nitroso-2-naphthylamine (5·16 g.) and 2-methoxycarbonylbenzyl cyanide (5·7 g.), and the mixture was boiled under reflux for 5 min. After cooling, the material was collected and dried (5·5 g.). Several crystallisations from acetic acid yielded the *3-hydroxy*-derivative as yellow needles, m. p. 362—363° (Found, after drying *in vacuo* at 150°: C, 76·7; H, 3·8; N, 14·05%). The acetic acid solution showed an intense blue fluorescence.

3-Chloro-4 : 9 : 10-triaza-1 : 2-5 : 6-dibenzanthracene (I; R = Cl).—The 3-hydroxy-derivative (1·0 g.), phosphoryl chloride (20 ml.), and phosphorus pentachloride (1·0 g.) were heated under reflux condenser for 30 min., during which the colour of the solution darkened, a tar was deposited, and evolution of hydrogen chloride ceased. The excess of phosphoryl chloride was removed and the residue was treated with crushed ice, a yellow material being obtained. After being washed, this was dried (P_2O_5) (yield, 1·3 g.), and several crystallisations from benzene yielded the *3-chloro*-derivative as flat yellow needles, m. p. 288° (Found, after drying *in vacuo* at 150°: C, 72·9; H, 3·4; N, 13·2. $C_{19}H_{10}N_3Cl$ requires C, 72·3; H, 3·2; N, 13·3%).

3-Amino-4 : 9 : 10-triaza-1 : 2-5 : 6-dibenzanthracene (I; R = NH_2).—To a solution of sodium (0·25 g.) in ethanol (25 ml.) were added 2-cyanobenzyl cyanide (1·56 g.) and 2-nitroso-1-naphthylamine (1·72 g.), and the mixture was boiled under reflux for 10 min. A black crystalline precipitate was formed (2·25 g.) which after several crystallisations from acetic acid yielded the *3-amino*-derivative as yellow plates, m. p. 338° (Found, on a sample dried *in vacuo* at 190°: C, 76·6; H, 4·2; N, 18·9. $C_{19}H_{13}N_4$ requires C, 77·0; H, 4·1; N, 18·9%). The acetic acid solution showed an intense yellow-green fluorescence.

3-Amino-4 : 9 : 10-triaza-1 : 2-7 : 8-dibenzanthracene (II; R = NH_2).—This *amine* (1·35 g.) was prepared as in the above experiment, from 1-nitroso-2-naphthylamine (1·72 g.), as yellow needles (from acetic acid), m. p. >360° (Found, on a sample dried *in vacuo* at 180°: C, 76·5; H, 4·2; N, 19·0%). The acetic acid solution showed an intense bright green fluorescence.

3-Mercapto-4 : 9 : 10-triaza-1 : 2-5 : 6-dibenzanthracene (I; R = SH).—3-Hydroxy-4 : 9 : 10-triaza-1 : 2-5 : 6-dibenzanthracene (1·5 g.), phosphorus pentasulphide (1·2 g.), and dry pyridine (20 ml.) were heated under reflux for 4 hr. The hot solution was filtered into boiling water (250 ml.), an orange precipitate being formed. Collection after cooling, and drying (yield, 1·5 g.), and recrystallisation from pyridine (charcoal) and then 2-ethoxyethanol gave the *3-thiol* as deep yellow needles, m. p. 352° (Found, after drying *in vacuo* at 180°: C, 72·85; H, 3·7; N, 13·3; S, 10·2. $C_{19}H_{11}N_3S$ requires C, 72·8; H, 3·5; N, 13·4; S, 10·2%).

3-Methylthio-4 : 9 : 10-triaza-1 : 2-5 : 6-dibenzanthracene (I; R = SMe).—The 3-thiol (I; R = SH) (1·0 g.) was dissolved in 2-ethoxyethanol (50 ml.) containing sodium (80 mg.), and the deep red solution was boiled under reflux for 5 min. When methyl iodide (1 ml.) was added the solution became bright yellow. After cooling, the yellow crystalline precipitate was collected and dried (0·87 g.). Several crystallisations from ethanol yielded the *3-methylthio*-derivative as bright yellow needles, m. p. 280° (Found, after drying *in vacuo* at 110°: C, 72·9; H, 4·2; N, 13·0; S, 9·5. $C_{20}H_{13}N_3S$ requires C, 73·4; H, 4·0; N, 12·8; S, 9·8%).

3-Anilino-4 : 9 : 10-triaza-1 : 2-5 : 6-dibenzanthracene (I; R = NHPh).—(*a*) The above 3-methylthio-derivative (0·4 g.) and aniline (2·5 ml.) were boiled under an air-condenser for 2·5 hr. during which evolution of methanethiol ceased. A yellow crystalline precipitate was deposited on cooling which was collected and crystallised several times from xylene (charcoal), to yield the *3-anilino*-derivative as bright yellow prisms, m. p. 282—283° (Found, on a sample dried *in vacuo* at 110°: C, 80·4; H, 4·2; N, 15·2. $C_{25}H_{16}N_4$ requires C, 80·6; H, 4·3; N, 15·05%).

(*b*) The 3-thiol (I; R = SH) (0·5 g.) and aniline (5 ml.) were boiled under an air-condenser for 8 hr. Working up as in the previous experiment yielded the 3-anilino-derivative, m. p. and mixed m. p. 282—283°.

The solution in xylene showed an intense blue-green fluorescence.

Dihydro-4 : 9 : 10-*triaza*-1 : 2-5 : 6-*dibenzanthracene*.—The 3-thiol (I; R = SH) (2·0 g.), freshly prepared Raney nickel (*ca.* 10 g., moist), and dioxan (150 ml.; 80%) were boiled vigorously under reflux for 6 hr. The hot solution was filtered and the Raney nickel was washed with acetone. The solution was concentrated, to give an orange material (1·5 g.). Several crystallisations from butanol yielded *dihydro*-4 : 9 : 10-*triaza*-1 : 2-5 : 6-*dibenzanthracene* as orange needles, m. p. 275° (Found, on a sample dried *in vacuo* at 110°: C, 80·6; H, 4·7; N, 14·7. $C_{19}H_{13}N_3$ requires C, 80·5; H, 4·6; N, 14·8%). The butanol solution showed a bright green fluorescence.

4 : 9 : 10-*Triaza*-1 : 2-5 : 6-*dibenzanthracene* (I; R = H).—(*a*) Palladium–charcoal (0·3 g.) and the above dihydro-derivative (0·3 g.) were mixed and sublimed at 280°/0·05 mm. A bright yellow powder was obtained. Two sublimations, followed by crystallisation from ethanol, yielded 4 : 9 : 10-*triaza*-1 : 2-5 : 6-*dibenzanthracene* as long yellow needles, m. p. 282—283° (Found, after drying *in vacuo* at 110°: C, 80·9; H, 3·8; N, 15·05. $C_{19}H_{11}N_3$ requires C, 81·1; H, 3·9; N, 14·9%).

(*b*) The dihydro-derivative (0·5 g.), dissolved in glacial acetic acid (100 ml.), at 90° was treated with sodium nitrite (3 g.) in water (6 ml.) with stirring, and the mixture boiled gently until all solid had dissolved. The product, precipitated by adding water, crystallised from ethanol in yellow needles (0·4 g.), m. p. 280°. After recrystallisation identity was indicated by mixed m. p. (Found, after drying *in vacuo* at 110°: C, 81·3; H, 3·9; N, 14·8%).

The solution in ethanol gave a bright blue fluorescence.

Hydrogenation in the presence of palladium–charcoal in acetic acid could not be achieved.

Reduction of the material in acetic acid with zinc dust in excess gave a deep red solution which became yellow when heated. Working up yielded the dihydro-derivative and starting material, identified by mixed m. p. Perhaps a free radical is initially formed and later disproportionates.

3-*Mercapto*-4 : 9 : 10-*triaza*-1 : 2-7 : 8-*dibenzanthracene* (II; R = SH).—The 3-hydroxy-derivative (II; R = OH) (1·5 g.), phosphorus pentasulphide (1·2 g.), and dry pyridine (30 ml.) were boiled under reflux for 4 hr. The mixture, which almost solidified, was kept overnight and then poured into boiling water (250 ml.), and the orange precipitate was collected and dried (1·55 g.). Several crystallisations from pyridine yielded the 3-*thiol* as orange needles, m. p. 317—318° (Found, on a sample dried *in vacuo* at 150°: C, 73·0; H, 3·5; N, 12·8; S, 9·8. $C_{19}H_{11}N_3S$ requires C, 72·8; H, 3·5; N, 13·4; S, 10·2%).

3-*Anilino*-4 : 9 : 10-*triaza*-1 : 2-7 : 8-*dibenzanthracene* (II; R = NHPh).—Aniline (5·0 ml.) and the 3-thiol (II; R = SH) (0·5 g.) were boiled under an air-condenser for 12 hr. during which time evolution of hydrogen sulphide ceased. After cooling, ether was added. The brown precipitate was crystallised several times from benzene (charcoal), to give the 3-*anilino*-derivative, m. p. 263° (Found, after drying *in vacuo* at 110°: C, 80·9; H, 4·4; N, 14·5. $C_{25}H_{16}N_4$ requires C, 80·6; H, 4·3; N, 15·05%).

Dihydro-4 : 9 : 10-*triaza*-1 : 2-7 : 8-*dibenzanthracene*.—A mixture of the 3-thiol (II; R = SH) (6·0 g.), freshly prepared Raney nickel (*ca.* 30 g., moist), and dioxan (60 ml.; 80%) was boiled vigorously under reflux for 6 hr. during which an intense green fluorescence developed and a bright yellow precipitate was deposited. The solution was filtered hot; crystals were then deposited (1·5 g.; m. p. 260°). The Raney nickel was continuously extracted with acetone, yielding a further 2·5 g. of material of m. p. 265°. The bulked materials were crystallised twice from butanol, to yield the *dihydro*-derivative, m. p. 275° as orange-yellow needles (Found, after drying *in vacuo* at 110°: C, 80·3; H, 4·3; N, 15·1. $C_{19}H_{13}N_3$ requires C, 80·5; H, 4·6; N, 14·8%). The butanol solution showed an intense bright green fluorescence.

4 : 9 : 10-*Triaza*-1 : 2-7 : 8-*dibenzanthracene* (II; R = H).—Palladium–charcoal (0·5 g.) and the above dihydro-compound (0·5 g.) were mixed and heated at 260°/0·05 mm. The bright yellow sublimate obtained was resublimed and then crystallised from butanol, to yield 4 : 9 : 10-*triaza*-1 : 2-7 : 8-*dibenzanthracene* as pale yellow rods, m. p. 293° (Found, after drying *in vacuo* at 150°: C, 81·0; H, 3·8; N, 15·0. $C_{19}H_{11}N_3$ requires C, 81·1; H, 3·9; N, 14·9%). The butanol solution showed an intense bright blue fluorescence.

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Quaternary Salts from 2-Chloro-5-nitropyrimidines. Part I. Preparation and Some Reactions.

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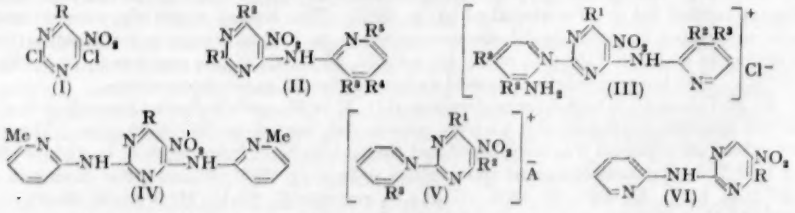
The reaction of several 2:4-dichloro- and 2-chloro-5-nitropyrimidines with pyridine, 2-aminopyridine, and 2-amino-3(or 4)-methylpyridine yielded, in general, quaternary salts formed *via* the 2-chloro-substituent of the pyrimidine; the 4-chloro-substituent (when present) condensed normally with the amino-group. When 2-amino-6-methylpyridine reacted with 2:4-dichloro-6-methyl- or 2:4-dichloro-5-nitropyrimidine no quaternary salt was formed; condensation occurred between the amino-group and, successively, the 4- and the 2-chloro-substituent. Replacement of the aminopyridyl substituent in the 2-position of the pyrimidine quaternary salts by alkoxy- and amino-groups was investigated.

REACTION of 2:4-dichloro- or 2:4-dichloro-6-methyl-5-nitropyrimidine (I; R = H or Me) with ammonia has led, according to the conditions, to substitution of one chlorine substituent, or of both, to yield 4-amino-2-chloro- or 4-amino-2-chloro-6-methyl-5-nitropyrimidine or the corresponding diaminopyrimidines (Gabriel and Colman, *Ber.*, 1901, **34**, 1244; Gabriel and Isay, *Ber.*, 1906, **39**, 230). Condensation of the dichloropyrimidines with α-amino-esters and -ketones has yielded analogous products (Boon, Ramage, and Jones, *J.*, 1951, **96**; Boon and Jones, *ibid.*, p. 591; Polonovski and Jerome, *Compt. rend.*, 1950, **230**, 392). In all cases the 4-chlorine atom in the pyrimidine is the first to be substituted. However, we found that the compound (I; R = H) (1 mol.) and 2-aminopyridine (2 mols.) gave only a small amount of the expected product (II; $R^1 = Cl$, $R^2 = R^3 = R^4 = R^5 = H$) in methanol at 0°, the main product being a yellow crystalline solid soluble in water, containing ionic chlorine, and derived from two mols. of 2-amine and one of the chloro-compound with the loss of one mol. of hydrochloric acid. Since the same compound was also obtained by treating a boiling solution of the base (II; $R^1 = Cl$, $R^2 = R^3 = R^4 = R^5 = H$) in methanol with one mol. of 2-aminopyridine, or by treating the pyrimidine (I; R = H) with three mols. of 2-aminopyridine in hot methanol, it appeared to be the quaternary salt (III; $R^1 = R^2 = R^3 = H$). Strong evidence for this structure and against formulation as the hydrochloride of 5-nitro-2:4-di-2′-pyridylaminopyrimidine is derived from the reaction of 2-amino-6-methylpyridine with 2:4-dichloro- or 2:4-dichloro-6-methyl-5-nitropyrimidine (see below) in hot methanol which



yields respectively the bases (IV; R = H or Me), insoluble in water. Finally the ultraviolet spectra of compounds (III; R^2 = Me, $R^1 = R^3 = H$) and (IV; R = H) show a very marked difference which could not exist unless the former was a quaternary salt;

thus the former in 0·05N-hydrochloric acid had maxima at 340 and 229 mμ (ε 9500 and 23,100 respectively) and a minimum 322 mμ (ε 9200), and the latter in 0·1N-hydrochloric acid had maxima at 330·5 and 239·5 (ε 29,800 and 13,800 respectively) and minima at 266·5 and 223·0 mμ (ε 7340 and 11,100 respectively).

Again, in methanol at 0°, the pyrimidine (I; R = Me) and 2-aminopyridine yielded an analogous quaternary salt (III; R^1 = Me, R^2 = R^3 = H).

When 2 : 4-dichloro-5-nitropyrimidine was treated in boiling methanol with 4 mols. of 2-aminopyridine the quaternary salt (III; R^1 = R^2 = R^3 = H) was precipitated initially but on continued boiling passed into solution. On cooling, a new compound, m. p. 148°, was precipitated. Since this was also formed when the quaternary salt was treated in boiling methanol with 2-aminopyridine, and when 2-chloro-5-nitro-4-2′-pyridylaminopyrimidine (II; R^1 = Cl, R^2 = R^3 = R^4 = R^5 = H) was treated with sodium methoxide in methanol, it is 2-methoxy-5-nitro-4-2′-pyridylaminopyrimidine (II; R^1 = MeO, R^2 = R^3 = R^4 = R^5 = H). Similar compounds were formed in boiling methanol from 2 : 4-dichloro-5-nitropyrimidine and the 3- and the 4-methyl homologue of 2-aminopyridine, and from 2 : 4-dichloro-6-methyl-5-nitropyrimidine. Reaction in boiling ethanol gave ethoxypyrimidines.

Confirmation that the 2-chlorine atom in the pyrimidine is involved in the quaternisation has been obtained in two ways. 2-Amino-4-chloro-6-methyl-5-nitropyrimidine, unequivocally synthesised by the action of phosphoryl chloride on 2-amino-4-hydroxy-6-methyl-5-nitropyrimidine (Boon, Ramage, and Jones, *J.*, 1951, 96), with 2-aminopyridine gave a product identical with that obtained by heating the quaternary salt (III; R^1 = Me, R^2 = R^3 = H) with methanolic ammonia. Again the quaternary salt (III; R^1 = R^2 = R^3 = H) with ammonia yielded what must be 2-amino-5-nitro-4-2′-pyridylaminopyrimidine (II; R^1 = NH_2, R^2 = R^3 = R^4 = R^5 = H) since it differs from the product (VI; R = NH_2) obtained from 4-amino-2-chloro-5-nitropyrimidine and 2-aminopyridine. Aniline reacted similarly with (III; R^1 = R^2 = R^3 = H). This evidence also confirms the structure (II; R^1 = Cl, R^2 = R^3 = R^4 = R^5 = H) for the minor product of the reaction of the pyrimidine (I; R = H) with 2-aminopyridine since, as shown earlier, the corresponding 2-methoxy-compound (II; R^1 = MeO, R^2 = R^3 = R^4 = R^5 = H) is obtained by replacement either of the chlorine atom in this compound or of the aminopyridine residue in the salt (III; R^1 = R^2 = R^3 = H) by a methoxy-group. The replacement by amino- or alkoxy-groups of the 2-aminopyridine residue in quaternary salts of the type described above provides a new approach to 2-amino- and 2-alkoxy-pyrimidines which will be further described later.

Returning now to the typical reaction involving formation of a quaternary salt, we sought to examine the effect of various substitutions in the aminopyridine and the pyrimidine component. From the reaction of the pyrimidine (I; R = Me) with 2-amino-3- and 2-amino-4-methylpyridine, only the salts (III; R^1 = R^3 = H, R^2 = Me, and R^1 = R^2 = H, R^3 = Me) were obtained; similarly 2-aminopyridine gave only the salt (III; R^1 = Me, R^2 = R^3 = H). However, neither of the dichloropyrimidines (I; R = H or Me) with 2-amino-6-methylpyridine gave a quaternary salt, one or both of the chlorine atoms being replaced by the methylpyridylamino-residue. The absence of quaternary salt formation may be attributed to a steric effect of methyl and substituted amino-groups which flank the pyridine nitrogen atom. Bergstrom and Siegel (*J. Amer. Chem. Soc.*, 1952, **74**, 254) point out that quaternisation of 2 : 4 : 6-trimethylpyridine by sulphonic acid esters is apparently slower than that of pyridine. Antaki and Petrov (*J.*, 1951, 551) found that ethyl β-aminocrotonate and 2-aminopyridine form 4 : 10-dihydro-2-methyl-4-oxo-1 : 10-diazanaphthalene and the same ring-closure occurs with amino-methylpyridines, with however the exception of 2-amino-6-methylpyridine where steric hindrance appears to prevent reaction. Lappin (*J. Amer. Chem. Soc.*, 1948, **70**, 3348) reported a similar effect when amino-methylpyridines react with ethoxymethylenemalonate. When 6-amino-2 : 4-dichloro-5-nitropyrimidine and 2-aminopyridine reacted at 0° no quaternisation was observed, the product being the base (II; R^2 = NH_2, R^1 = Cl, R^3 = R^4 = R^5 = H). Prolonged reaction at room temperature produced a mixture of this compound and the quaternary salt (III; R^1 = NH_2, R^2 = R^3 = H).

Other quaternary salts have been made from pyridine or 2-aminopyridine and 2-chloropyrimidines in benzene or acetone (see Experimental Section).

Quaternary salts which show some analogy with ours were made by Zincke (*Annalen*, 1904, **330**, 361), Zincke, Heuser, and Möller (*ibid.*, 1904, **333**, 296) (who used pyridine) and Vompe and Turitsyna (*Doklady Akad. Nauk S.S.S.R.*, 1950, **74**, 509; *Chem. Abs.*, 1951, **45**, 3846) (who used 3- and 4-aminopyridine) for reaction with 1-chloro-2 : 4-dinitrobenzene. With 2-aminopyridine, however, only 2-(2 : 4-dinitrophenylamino)pyridine was formed. The fact that no quaternary salt was formed in this case was attributed by Vompe and Turitsyna to a steric hindering effect involving, perhaps, both the pyridine-amino-group and the *o*-nitro-group in the chlorodinitrobenzene. This postulate could be applied to our experiences since this *o*-nitro-group could have a greater *ortho*-effect than the annular nitrogen atom of the 2-chloro-5-nitropyrimidines. We have found that quaternary salt formation occurs only with the 2- and not with the 4-chlorine atom, which could be hindered by the 5-nitro-group. In a preliminary publication (*Chem. and Ind.*, 1951, 937) we mentioned some of the points dealt with in this paper.

Experimental

M. p.s were determined in an electrically heated copper block.

Reaction of **2 : 4-*Dichloro-5-nitropyrimidine with* 2-*Aminopyridine.***—(a) *With* **2** *mols. of* 2-*aminopyridine.* To an ice-cold solution of 2 : 4-dichloro-5-nitropyrimidine (4·2 g.) in methanol (25 ml.) was slowly added an ice-cold solution of 2-aminopyridine (4·1 g.) in methanol (25 ml.). A yellow solid rapidly separated; after 2 hr. at 0° it was collected and washed with methanol. This solid (4·8 g.) was separated by hot water into the insoluble *2-chloro-5-nitro-4-2′-pyridylaminopyrimidine* (0·9 g.), yellow sword-shaped prisms (from ethanol), m. p. 156° (Found: C, 43·3; H, 2·6; N, 27·2. $C_9H_6O_2N_5Cl$ requires C, 43·0; H, 2·4; N, 27·8%), and the *2-amino-1-(5-nitro-4-2′-pyridylamino-2-pyrimidyl)pyridinium chloride* (III; $R^1 = R^2 = R^3 = H$) (3·6 g.), yellow prismatic needles (from water or, better, dilute hydrochloric acid), m. p. 249° (decomp.) (Found: C, 49·1; H, 3·5; N, 28·25; Cl^-, 10·4. $C_{14}H_{12}O_2N_7Cl$ requires C, 48·8; H, 3·2; N, 28·4; Cl, 10·3%). The latter affords the *bromide*, needles (from water), m. p. 262° (decomp.) (Found: C, 42·8; H, 3·9; N, 23·95. $C_{14}H_{12}O_2N_7Br$ requires C, 43·2; H, 2·85; N, 25·1%), and *iodide*, orange needles (from water), m. p. 252° (decomp.) (Found: C, 38·5; H, 3·2; N, 21·1. $C_{14}H_{12}O_2N_7I$ requires C, 38·85; H, 2·5; N, 22·4%).

(b) *With* **3** *mols. of* **2**-*aminopyridine.* From the reactants in boiling methanol the quaternary chloride separated quantitatively [m. p. 249° (decomp.)].

2-Chloro-5-nitro-4-2′-pyridylaminopyrimidine (0·2 g.) and 2-aminopyridine (0·4 g.) in hot methanol (15 ml.) gave the same chloride immediately, having m. p. 249° (decomp.) (Found: N, 28·0%).

(c) *With* **4** *mols. of* **2**-*aminopyridine.* When to a hot solution of 2 : 4-dichloro-5-nitropyrimidine (0·98 g.) in methanol (25 ml.) was added 2-aminopyridine (1·9 g.), the quaternary chloride separated. Continued boiling, however, gave a clear solution which on cooling deposited a pale yellow solid. Crystallisation of this solid from ethanol gave 2-methoxy-5-nitro-4-2′-pyridylaminopyrimidine, m. p. 148° alone or mixed with the compound prepared as below.

2-Methoxy-5-nitro-4-2′-pyridylaminopyrimidine.—To a solution of sodium (0·5 g.) in methanol (10 ml.) was added a solution of 2-chloro-5-nitro-4-2′-pyridylaminopyrimidine (0·5 g.) in methanol (15 ml.), and the resulting orange-red solution refluxed for 2 hr. The solution was acidified with dilute acetic acid and cooled and the yellow solid collected and washed with water. Crystallisation from ethanol gave yellow plates of *2-methoxy-5-nitro-4-2′-pyridylaminopyrimidine*, m. p. 148° (Found: C, 48·5; H, 3·9; N, 28·6. $C_{10}H_9O_3N_5$ requires C, 48·6; H, 3·7; N, 28·3%).

2-Ethoxy-5-nitro-4-2′-pyridylaminopyrimidine.—The 2-chloro-compound was boiled with a solution of sodium ethoxide in ethanol for 2 hr. The *2-ethoxypyrimidine* crystallised from ethanol as pale yellow needles, m. p. 131° (Found: C, 51·0; H, 4·95; N, 27·5. $C_{11}H_{11}O_3N_5$ requires C, 50·6; H, 4·25; N, 26·8%).

This pyrimidine, m. p. and mixed m. p. 131°, was also obtained when the quaternary chloride (III; $R^1 = R^2 = R^3 = H$) was refluxed with 2-aminopyridine in ethanol.

Reaction of **2 : 4-*Dichloro-6-methyl-5-nitropyrimidine and* 2-*Aminopyridine.***—The *salt* (III; $R^1 = Me$, $R^2 = R^3 = H$) was obtained exclusively when the dichloro-compound was treated with 2-aminopyridine in ice cold methanol. It crystallised from water containing a few drops

of dilute hydrochloric acid in yellow needles, m. p. 215° (decomp.) (Found : C, 49·5; H, 4·0; N, 26·75. $C_{13}H_{14}O_3N_7Cl$ requires C, 50·0; H, 3·9; N, 27·2%).

4 Mols. of 2-aminopyridine and 1 mol. of the dichloropyrimidine, when refluxed in methanol, gave *2-methoxy-6-methyl-5-nitro-4-2′-pyridylaminopyrimidine*, yellow prisms (from ethanol), m. p. 137° (Found : C, 50·7; H, 5·01; N, 26·53. $C_{11}H_{11}O_3N_5$ requires C, 50·6; H, 4·25; N, 26·8%).

Reaction in ethanol gave a deep red solution. This was evaporated to dryness, the residue was exhaustively extracted with hot benzene, and the cooled extract filtered through a column of alumina. The yellow eluate was evaporated to dryness, and the residue crystallised from ethanol, to yield yellow needles of *2-ethoxy-6-methyl-5-nitro-4-2′-pyridylaminopyrimidine*, m. p. 113—114° (Found : C, 53·2; H, 4·8; N, 26·4. $C_{12}H_{13}O_3N_5$ requires C, 52·4; H, 4·8; N, 25·5%).

4-Amino-5-nitro-2-2′-pyridylaminopyrimidine.—2-Chloro-4-amino-5-nitropyrimidine (0·5 g.) (Isay, *Ber.*, 1906, **39**, 250) and 2-aminopyridine (1 g.) were heated at 120—130° for 1 hr. The melt was then triturated with 50% ethanol and the brown solid collected, dissolved in hot N/20-hydrochloric acid, and reprecipitated with ammonia. *4-Amino-5-nitro-2-2′-pyridylaminopyrimidine* crystallised from aqueous pyridine as pale yellow needles, m. p. 276° (Found : N, 36·5. $C_9H_8O_2N_6$ requires N, 36·2%).

2-Amino-5-nitro-4-2′-pyridylaminopyrimidine.—(*a*) 2-Chloro-5-nitro-4-2′-pyridylaminopyrimidine (0·5 g.) was refluxed for 2 hr. with methanolic ammonia (15 ml. of a saturated solution of ammonia in methanol, and 15 ml. of methanol). The bright yellow precipitated *2-amino-compound* crystallised from butan-1-ol as yellow plates, m. p. 251—252° (Found : C, 46·3; H, 3·9; N, 36·0. $C_9H_8O_2N_6$ requires C, 46·5; H, 3·5; N, 36·2%).

(*b*) A suspension of the quaternary salt (III; $R^1 = R^2 = R^3 = H$) (0·5 g.) in methanol (20 ml.) was treated with concentrated ammonia solution (3 ml.), a deep red solution being obtained. After 2 hours' refluxing the solution had become pale yellow and, on cooling, yellow plates of 2-amino-5-nitro-4-2′-pyridylaminopyrimidine (0·3 g.) separated, having m. p. and mixed m. p. 251—252°.

2-Anilino-5-nitro-4-2′-pyridylaminopyrimidine.—The quaternary salt (III; $R^1 = R^2 = R^3 = H$) (0·5 g.) was refluxed for 2 hr. in ethanol (20 ml.) containing aniline (2 ml.). The solid slowly dissolved and after a short time the anilinopyrimidine began to separate. The *2-anilinopyrimidine* crystallised from ethanol in yellow needles, m. p. 218° (Found : C, 59·6; H, 4·8; N, 25·7. $C_{16}H_{14}O_2N_6$ requires C, 59·6; H, 4·4; N, 26·1%). A better solvent for this reaction was 50% aqueous acetone. This pyrimidine could also be obtained by shaking the quaternary salt with ethanol and aniline at room temperature for 2 hr., or by heating the quaternary salt with aniline at 125° for 10 min.

2-Amino-6-methyl-5-nitro-4-2′-pyridylaminopyrimidine.—(*a*) The quaternary salt (III; $R^2 = R^3 = H$, $R^1 = Me$) (1 g.) was heated at 100° in saturated methanolic ammonia (25 ml.) in a sealed tube for 1 hr. The solution was cooled and the solid was collected. The product crystallised from butan-1-ol as yellow prisms, m. p. 230° alone or mixed with the compound prepared as follows.

(*b*) 2-Amino-4-chloro-6-methyl-5-nitropyrimidine (Boon *et al.*, *loc. cit.*) (0·2 g.) and 2-aminopyridine (0·4 g.) were heated at 125° for ½ hr. The melt was triturated with ethanol, the solid was filtered off, and *2-amino-6-methyl-5-nitro-4-2′-pyridylaminopyrimidine* crystallised from butan-1-ol (m. p. 230°) (Found : C, 49·0; H, 4·5; N, 33·9. $C_{10}H_{10}O_2N_6$ requires C, 48·8; H, 4·1; N, 34·1%).

Reaction of 2 : 4-*Dichloro-5-nitropyrimidine with 2-Amino-6-methylpyridine.*—(a) *With 2 mols. of 2-amino-6-methylpyridine.* Solutions of 2-amino-6-methylpyridine (1·9 g.) in methanol 20 (ml.) and of 2 : 4-dichloro-5-nitropyrimidine (2 g.) in methanol (20 ml.) were mixed and set aside for 2 hr. at 0°. The precipitate was crystallised from ethanol, to give *2-chloro-4-(6-methyl-2-pyridylamino)-5-nitropyrimidine* (2 g.) in yellow needles, m. p. 144° (Found : C, 45·2; H, 3·35; N, 25·7. $C_{10}H_8O_2N_5Cl$ requires C, 45·2; H, 3·0; N, 26·4%).

(b) *With 4 mols. of 2-amino-6-methylpyridine.* After the reactants had been boiled in methanol for 5 hr. and then cooled, the precipitate was crystallised from glacial acetic acid, to give 2 : 4-*di*-(*6-methyl-2-pyridylamino*)-*5-nitropyrimidine*, m. p. 318°, yellow needles (Found : C, 56·9; H, 4·5; N, 28·8. $C_{16}H_{15}O_2N_7$ requires C, 57·0; H, 4·5; N, 29·1%).

Reaction of 2 : 4-*Dichloro-5-nitropyrimidine with 2-Amino-3-methylpyridine.*—When this reaction was carried out in methanol solution at 0° with 2—3 mols. of the pyridine the only product was the *salt* (III; $R^1 = H$, $R^2 = Me$, $R^3 = H$) which crystallised from water in yellow prisms, m. p. 250° (decomp.) (Found : C, 51·4; H, 4·5; N, 26·6. $C_{16}H_{16}O_2N_7Cl$ requires C, 51·4; H, 4·3; N, 26·4%).

If one mol. of the dichloro-compound was refluxed with 4 mols. of 2-amino-3-methylpyridine in boiling methanol solution the product was *2-methoxy-4-(3-methyl-2-pyridylamino)-5-nitropyrimidine* which crystallised from water [or, better, light petroleum (b. p. 40—60°)] as yellow prisms, m. p. 110° (Found: C, 50·4; H, 4·5; N, 26·9. $C_{11}H_{11}O_3N_5$ requires C, 50·6; H, 4·2; N, 26·8%).

Reaction of 2 : 4-*Dichloro-5-nitropyrimidine with* 2-*Amino-4-methylpyridine.*—The dichloro-compound was treated with 3 mols. of the base in ice-cold methanol to give the *salt* (III; $R^1 = R^2 = H$, $R^3 = Me$), m. p. 237—238° (decomp.), yellow prisms (from water) (Found: C, 51·7; H, 4·6; N, 26·0. $C_{16}H_{16}O_2N_7Cl$ requires C, 51·4; H, 4·3; N, 26·2%).

When the dichloropyrimidine was refluxed with 4 mols. of 2-amino-4-methylpyridine in hot methanol *2-methoxy-4-(4-methyl-2-pyridylamino)-5-nitropyrimidine* was obtained as yellow prisms (from butan-1-ol), m. p. 180° (Found: C, 50·65; H, 4·35; N, 27·3. $C_{11}H_{11}O_3N_5$ requires C, 50·6; H, 4·2; N, 26·8%).

Reaction of 2 : 4-*Dichloro-6-methyl-5-nitropyrimidine with* 2-*Amino-6-methylpyridine.*—(*a*) The dichloropyrimidine (2·08 g.) was dissolved in ether (30 ml.), and 2-amino-6-methylpyridine (2·16 g.) in methanol (30 ml.) was added. After 1 hr. at 0° the ether was removed and the solution was diluted with water, giving *2-chloro-6-methyl-4-(6-methyl-2-pyridylamino)-5-nitropyrimidine* (2 g.), m. p. 120°, yellow needles (from ethanol) (Found: C, 46·8; H, 3·8; N, 24·0. $C_{11}H_{10}O_2N_5Cl$ requires C, 47·2; H, 3·6; N, 25·05%).

(*b*) The dichloropyrimidine was refluxed with 4 mols. of 2-amino-6-methylpyridine in methanol, to give *6-methyl-2 : 4-di-(6-methyl-2-pyridylamino)-5-nitropyrimidine*, m. p. 180°, yellow needles (from ethanol) (Found: C, 58·2; H, 5·05. $C_{17}H_{17}O_2N_7$ requires C, 58·1; H, 4·9%).

Reaction of 6-*Amino-2 : 4-dichloro-5-nitropyrimidine with* 2-*Aminopyridine.*—(*a*) Keeping 6-amino-2 : 4-dichloro-5-nitropyrimidine (1 g.) and 2-aminopyridine (1·4 g., 3 mols.) in acetone (30 ml.) for 4 days at room temperature, evaporating the solution and extracting the residual solid with hot water gave a residue A (0·3 g.). The hot aqueous filtrate was treated with charcoal, filtered, and cooled; a solid B (1 g.) separated.

Solid A, crystallised from butan-1-ol, gave *6-amino-2-chloro-4-2′-pyridylamino-5-nitropyrimidine* as yellow needles, m. p. 239° (Found: C, 40·8; H, 2·8; N, 31·8. $C_9H_7O_2N_6Cl$ requires C, 40·5; H, 2·65; N, 31·5%).

Solid B, crystallised from ethanol–ether, yielded the *chloride* (III; $R^1 = NH_2$, $R^2 = R^3 = H$) as yellow prisms, m. p. 271° (decomp.) (Found: C, 46·3; H, 3·7; N, 30·4. $C_{14}H_{13}O_2N_6Cl$ requires C, 46·6; H, 3·6; N, 31·1%). The *iodide* crystallised from water in orange prisms, m. p. 265° (decomp.) (Found: C, 37·3; H, 3·3; N, 25·0. $C_{14}H_{13}O_2N_6I$ requires C, 37·2; H, 2·9; N, 24·8%).

(*b*) Reaction with 2 mols. of 2-aminopyridine in ice-cold ethanol gave only 6-amino-2-chloro-4-2′-pyridylamino-5-nitropyrimidine, m. p. and mixed m. p. 239°.

Preparation of Quaternary Salts from 2-*Chloropyrimidines.*—2-Chloro-5-nitro-4-2′-pyridylaminopyrimidine (0·5 g.), dissolved in hot benzene (25 ml.) and treated with pyridine (0·7 ml.), gave, on cooling, *1-(5-nitro-4-2′-pyridylamino-2-pyrimidyl)pyridinium chloride* (V; R^2 = 2′-pyridylamino, $R^1 = R^3 = H$, A = Cl) (0·6 g.) as a yellow semi-crystalline solid which crystallised from ethanol–ether in yellow prisms, m. p. 220° (decomp.) (dependent on rate of heating) (Found: C, 51·2; H, 3·35; N, 25·1. $C_{14}H_{11}O_2N_6Cl$ requires C, 50·8; H, 3·35; N, 25·4%).

To a solution of 4-anilino-2-chloro-5-nitropyrimidine (0·3 g.) in hot benzene (20 ml.) was added pyridine (0·5 ml.). An aqueous solution of the salt, precipitated on cooling, was treated with a saturated solution of sodium iodide; the *pyridinium iodide* (0·2 g.) (V; R^2 = Ph·NH, $R^1 = R^3 = H$, A = I) separated. It crystallised from water in orange plates, m. p. 215° (decomp.) (Found: C, 42·2; H, 3·2; N, 17·0. $C_{15}H_{12}O_2N_5I$ requires C, 42·9; H, 2·9; N, 16·7%).

2-Chloro-4-(6-methyl-2-pyridylamino)-5-nitropyrimidine and pyridine in benzene yielded the *chloride* (V; R^2 = 6-methyl-2-pyridylamino, $R^1 = R^3 = H$, A = Cl), yellow needles (from ethanol–ether), m. p. 200° (decomp.) (Found: C, 52·4; H, 4·2; N, 24·4. $C_{15}H_{13}O_2N_6Cl$ requires C, 52·2; H, 3·8; N, 24·4%).

When 2-chloro-6-methyl-4-(6-methyl-2-pyridylamino)-5-nitropyrimidine and pyridine were mixed in hot benzene solution a dark solid was obtained. This was extracted with water (charcoal), and the pale yellow extract, treated with a saturated solution of sodium iodide, gave the *quaternary iodide* (V; R^2 = 6-methyl-2-pyridylamino, R^1 = Me, R^3 = H, A = I), scarlet needles (from water), m. p. 224° (decomp.) (Found: C, 42·9; H, 4·5; N, 19·1. $C_{16}H_{15}O_2N_6I$ requires C, 42·7; H, 3·4; N, 18·7%).

The *salt* (V; $R^2 = NH_2$, $R^1 = R^3 = H$, A = Cl) was prepared from the components in acetone and crystallised from ethanol–ether in buff needles, m. p. 255—256° (decomp.) (Found: C, 42·0; H, 3·5; N, 27·45. $C_9H_9O_2N_5Cl$ requires C, 42·6; H, 3·2; N, 27·6%). Similarly were prepared the *chlorides* (V; $R^2 = R^3 = NH_2$, $R^1 = H$, A = Cl), pale orange-yellow rods (from water), m. p. 273—274° (decomp.) (Found: C, 40·7; H, 3·5; N, 31·1. $C_9H_9O_2N_6Cl$ requires C, 40·2; H, 3·4; N, 31·35%), (V; R^2 = Ph·NH, $R^1 = H$, $R^3 = NH_2$, A = Cl), yellow prisms (from ethanol–ether), m. p. 200—202° (decomp.) (Found: C, 51·8; H, 4·2; N, 23·9. $C_{15}H_{13}O_2N_6Cl$ requires C, 52·2; H, 3·8; N, 24·4%), and (V; R^2 = 6-methyl-2-pyridylamino, $R^1 = H$, $R^3 = NH_2$, A = Cl), yellow prisms (from ethanol–ether), m. p. 222—223° (decomp.) (Found: C, 49·8; H, 4·3; N, 27·7. $C_{13}H_{14}O_2N_7Cl$ requires C, 50·1; H, 3·9; N, 27·3%).

The *iodides* corresponding to the last two crystallised from water in orange rods, m. p. 213—214° (decomp.) (Found: C, 41·3; H, 2·7; N, 19·9. $C_{15}H_{13}O_2N_6I$ requires C, 41·3; H, 3·0; N, 19·3%), and orange needles, m. p. 252° (decomp.) (Found: C, 39·6; H, 2·3; N, 21·1. $C_{13}H_{14}O_2N_7I$ requires C, 39·9; H, 3·1; N, 21·7 %), respectively.

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Mesomorphism and Chemical Constitution. Part VI. Certain Mono- and Di-anils of the Benzene, Diphenyl, Fluorene, and Fluorenone Series.*

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Although the anils derived from aniline and *p*-*n*-alkoxybenzaldehydes are not mesomorphic, the corresponding anils from 4-aminodiphenyl exhibit phases of appreciable thermal stability, and the mesophases of the dianils of benzidine are much more stable than those of *p*-phenylenediamine. These observations confirm the earlier view that diphenyl derivatives display a greater tendency than benzene systems to produce mesophases of high thermal stability. The monoanils from 2-amino-fluorene and -fluorenone, and the dianils from 2 : 7-diamino-fluorene and -fluorenone are also mesomorphic, and an attempt has been made to relate their mesomorphic behaviour to recent interpretations of the structure of fluorene and fluorenone.

The effects of structure on the mesomorphic behaviour of certain substituted and unsubstituted alkoxyarenecarboxylic acids have been discussed in preceding Parts of this series. By using the mesomorphic transition temperatures as an indication of the relative thermal stabilities of the phases, it has been possible to establish the effect of different aromatic ring systems, both substituted and unsubstituted, on the mesomorphic stability, and to show that the thermal stabilities of analogous derivatives based on diphenyl are greater than those derived from naphthalene which, in turn, are greater than those based on benzene. In an attempt to extend this series, it was decided to investigate the 7-alkoxy-fluorene- and -fluorenone-2-carboxylic acids. That these tricyclic systems would yield mesomorphic derivatives was by no means certain, for while the fluorene molecule, and probably that of fluorenone, would appear to be planar, *X*-ray studies suggest that they are distorted (Iball and Burns, *Nature*, **1954**, **173**, 635). If this is so, then a 2 : 7-disubstituted fluorene would not be strictly linear. Unfortunately the synthesis of these acids is not straightforward and, in case they should fail to exhibit mesomorphism, the more readily accessible anils

* Part V, *J.*, 1955, 1412.

from 2-amino-fluorene and -fluorenone with *p*-alkoxybenzaldehydes were first examined. The pronounced mesomorphism of these Schiff's bases made it seem highly likely that the fluorene- and fluorenone-carboxylic acids would exhibit mesomorphism, and the synthesis of the acids and examination of their mesomorphic properties are now in progress. The behaviour of the anils themselves however is of interest, and they are here compared with corresponding anils derived from aniline and 4-aminodiphenyl.

A homologous series of anils was prepared by condensation of the methyl to decyl, dodecyl, hexadecyl, and octadecyl ethers of *p*-hydroxybenzaldehyde with the amine. Among the monoanils, the *p*-alkoxybenzylideneanilines show no mesomorphism, and here a representative few (containing the alkyl groups methyl, heptyl, dodecyl, hexadecyl, and octadecyl) were prepared to establish the complete absence of anisotropy. Their m. p.s are included in the Experimental section.

All thirteen anils in each of the series of 4-*p*-alkoxybenzylideneaminodiphenyls and 2-*p*-alkoxybenzylideneamino-fluorenes and -fluorenones are mesomorphic, and their m. p.s and mesomorphic transition temperatures are summarised in Tables 1, 2, and 3 respectively. In the first two of these three series, the plots of the mesomorphic transition temperatures against the number of carbon atoms in the *n*-alkyl chain show the usual regularities found

TABLE 1. 4-p-n-*Alkoxybenzylideneaminodiphenyls.*

	Temp. of transition to				Temp. of transition to		
Alkyl	smectic	nematic	isotropic	Alkyl	smectic	nematic	isotropic
Methyl	—	161·5°	173·5°	Octyl	142·5°	155·5°	164°
Ethyl	—	146·5	190	Nonyl	140·5	157	160·5
Propyl	—	154·5	170	Decyl	140	157·5	159·5
Butyl	—	147·5	176	Dodecyl	137·5	—	155·5
Pentyl	137°	137·5	167	Hexadecyl	121	—	149
Hexyl	132	146	168·5	Octadecyl	124	—	146
Heptyl	141·5	151·5	163·5				

TABLE 2. 2-p-n-*Alkoxybenzylideneaminofluorenes.*

	Temp. of transition to				Temp. of transition to		
Alkyl	smectic	nematic	isotropic	Alkyl	smectic	nematic	isotropic
Methyl	—	169·5°	211·5°	Octyl	117·5°	165·5°	189·5°
Ethyl	—	154	221·5	Nonyl	116·5	169	184
Propyl	—	156	204·5	Decyl	115	170·5	181
Butyl	—	140	208·5	Dodecyl	112·5	171	174
Pentyl	132°	137	197	Hexadecyl	113	—	164·5
Hexyl	125	149·5	198·5	Octadecyl	118	—	160·5
Heptyl	121·5	159	191				

TABLE 3. 2-p-n-*Alkoxybenzylideneaminofluorenones.*

	Temp. of transition to				Temp. of transition to		
Alkyl	smectic	nematic	isotropic	Alkyl	smectic	nematic	isotropic
Methyl	—	(141°)	157°	Octyl	(70°)	86°	142°
Ethyl	—	141·5	155	Nonyl	(80)	88·5	138·5
Propyl	—	130·5	132·5	Decyl	88·5	89	139·5
Butyl	—	110·5	146·5	Dodecyl	92	103·5	136
Pentyl	—	115·5	138	Hexadecyl	95·5	121·5	130·5
Hexyl	—	119·5	145	Octadecyl	101·8	123·5	129·5
Heptyl	(54°)	90	139·5				

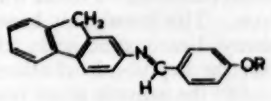
in other homologous series. The nematic and smectic–isotropic transition points lie on two falling curves, the lower referring to ethers with an odd and the upper to those with an even number of carbon atoms in the alkyl chain. The alternation of these transition points between odd and even members is appreciable in both series. It is, of course, absent in the smectic–nematic transition points, which lie on smooth rising curves, and these become coincident with the upper transition-point curves for the even members.

The last of the three series, the 2-*p*-alkoxybenzylideneaminofluorenones, appears to behave abnormally when a similar plot is made of their mesomorphic transition temperatures against the *n*-alkyl chain length. The smectic–nematic points constitute the normal rising curve, which, although it is steep, fails to become coincident with the upper

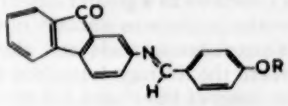
curve for the transition points. In other words, nematic properties persist even in the hexadecyl and the octadecyl ether. Further, the nematic–isotropic transition points do not conform to the usual pattern of two smoothly falling curves. Possible reasons for this behaviour are discussed later in this section, where the plot of these transition temperatures is represented in the Figure.

In the 2-*p*-alkoxybenzylideneaminofluorenones, monotropic properties are found in the nematic phase of the methyl ether, and in the smectic phases of the heptyl, octyl, and nonyl ethers. These monotropic transitions are recorded in parentheses.

It must be borne in mind that, as a result of the stereochemistry of the –CH=N– link, the anils are not strictly linear, and a comparison of their relative behaviours is consequently even less straightforward than that of various linear alkoxyarenecarboxylic acids. Therefore the suggested explanations of the relative stabilities of the mesophases in the anils must be tentative. Further, since free rotation cannot be considered with certainty to occur in a mesophase, it is necessary to assume that, both as solid and as mesomorphic melts, the molecules of the monoanils of fluorene (I) and fluorenone (II) adopt a *trans*-configuration, which is probably their lowest potential-energy state, and that fluorenone is distorted to the degree suggested by Iball and Burns (*loc. cit.*) for fluorene.



(I)



(II)

The absence of mesomorphism in the *p*-alkoxybenzylideneanilines, and the occurrence of considerably stable mesophases in the 4-*p*-alkoxybenzylideneaminodiphenyls again emphasise the greater mesomorphic stability of a diphenyl structure. To test this view further, and to obtain figures comparable with those for the *p*-alkoxybenzoic acids and the 4′-alkoxydiphenyl-4-carboxylic acids (Gray, Hartley, and Brynmor Jones, *J.*, 1955, 1412), the dianils derived from *p*-phenylenediamine and from 4 : 4′-diaminodiphenyl were examined. The results (m. p.s and mesomorphic transition temperatures) are summarised in Tables 4 and 5.

TABLE 4. NN′-*Di*-(p-n-*alkoxybenzylidene*)-p-*phenylenediamines*.

	Temp. of transition to				Temp. of transition to		
Alkyl	smectic	nematic	isotropic	Alkyl	smectic	nematic	isotropic
Methyl	—	214·5°	> 330°	Octyl	160°	209°	238°
Ethyl	—	202·5	> 330	Nonyl	150·8	211·5	228
Propyl	—	193	313	Decyl	145·5	212	222
Butyl	—	186·5	297·5	Dodecyl	137·5	208	209
Pentyl	(171·5°)	175	271	Hexadecyl	127·5	—	191
Hexyl	169·5	189	259·5	Octadecyl	135·5	—	187
Heptyl	164·5	202·5	245				

TABLE 5. 4 : 4′-*Di*-(p-n-*alkoxybenzylideneamino*)*diphenyls*.

	Temp. of transition to				Temp. of transition to		
Alkyl	smectic	nematic	isotropic	Alkyl	smectic	nematic	isotropic
Methyl	—	266°	> 390°	Octyl	202·5°	314°	353°
Ethyl	—	239	> 390	Nonyl	204·5	314	338
Propyl	—	255·5	> 390	Decyl	202·5	311·5	324
Butyl	264°	280·5	> 390	Dodecyl	187	301	302·5
Pentyl	244	301	393·5	Hexadecyl	177·5	—	280·5
Hexyl	221	308	384·8	Octadecyl	175·5	—	271·5
Heptyl	214	312·5	365				

In the phenylenediamine series, the very high thermal stability of the phases made it impossible to determine the nematic–isotropic transition temperatures for the methyl and ethyl ethers since in the nematic phases they sublimed and decomposed rapidly at about 330°.

The nematic–isotropic transition temperatures of the first three members of the diaminodiphenyl series, which are purely nematic, and of the butyl ether, which exhibits an additional smectic phase, could not be determined because of the high thermal stability of the nematic phases and their subsequent decomposition on further heating.

In order to compare the dianils of the diphenyl series with those of benzene, the average smectic–nematic and nematic–isotropic transition temperatures for the heptyl—decyl ethers (inclusive) have been calculated in each case. These values give an indication of the relative stabilities of the smectic and the nematic phase in the two series.

Average transition temp. (C_7—C_{10})	Dianils of benzene	Dianils of diphenyl	Increase
Smectic–nematic	208·8°	313°	104·2°
Nematic–isotropic	233·3	345	111·7

The incorporation of the second benzene ring in the diphenyl dianils increases the relative stability of the nematic phase by 111·7°, and of the smectic phase by 104·2°. The stability increases are appreciable in both cases, but the increase is greater in the nematic phase. At first this seems surprising, since intermolecular cohesions arising from the polarisability of the second ring in diphenyl would be expected to increase the lateral and planar cohesions to a greater extent than the terminal cohesions—a result which would lead to a greater increase in stability of the smectic phase. This has already been observed for the *p*-alkoxybenzoic acids and the 4′-alkoxydiphenyl-4-carboxylic acids (cf. Part V, *loc. cit.*), where the average transition temperatures for the heptyl—decyl ethers indicate stability increases of 143·5° and 116·9°, for the smectic and the nematic phase respectively. These increases are a result of a change from two to four benzene rings in the "dimers" of the benzoic and diphenic acids. The increases are therefore larger than those involved in passing from a benzene dianil (3 benzene rings) to a diphenyl dianil (4 benzene rings).

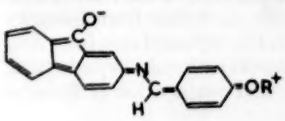
On this basis the relative stability of the nematic phases in the diphenyl dianils is larger than would be expected. The reason for this may be that the 1 : 1′-bond in diphenyl has enough double-bond character to make possible a fully conjugated system in a diphenyl dianil. In the 4′-alkoxydiphenyl-4-carboxylic acids the hydrogen bonds will not transmit the effects of conjugation in the two monomer units. It would seem, therefore, that the polarisability of a diphenyl dianil in the direction of its long axis could be greater than expected—a result which would be reflected in an enhancement of nematic stability. This could account for the differences in the behaviour of benzoic and diphenic acids on the one hand and of anils on the other. Apart from these considerations, the behaviour of these dianils emphasises the high mesomorphic stability of the phases produced by derivatives of diphenyl which are at least approximately linear in character. For a comparison of the monoanils of the fluorene (Table 2) and the fluorenone series (Table 3) with those of the diphenyl series an indication of the relative thermal stabilities in the three series is again obtained by averaging separately the smectic–nematic and nematic–isotropic transition temperatures for four ethers (heptyl—decyl) in each case. These averages, with the appropriate decreases in the average transition temperatures, are annexed.

Average transition temp. (C_7—C_{10})	Monoanils from fluorene		Monoanils from diphenyl		Monoanils from fluorenone
Smectic–nematic	166°	10·6°	155·4°	82·1°	73·3°
Nematic–isotropic	186·4	24·5	161·9	22	139·9

These average transition temperatures indicate the order of decreasing thermal stability, with respect to both phase types, to be fluorene, diphenyl, fluorenone. Thus, despite the distortion of the fluorene molecule from linearity (Iball and Burns, *loc. cit.*), the monoanils of fluorene exhibit the most stable mesophases. Scale drawings of 2-*p*-alkoxybenzylideneaminofluorenes show that the molecules are broader than the analogous 4-*p*-alkoxybenzylideneaminodiphenyls by 1·23—1·24 Å. Such an effect would be expected to decrease the thermal stability (Gray and Brynmor Jones, *J.*, 1954, 2556; 1955, 236), and it is obvious that some other influence must be operating to counteract the effect of an increase in breadth, so that the overall result is an increase in intermolecular cohesion. A fluorene

monoanil has a higher calculated polarisability than a diphenyl monoanil, and the exaltation of the molecular refraction (2·56 c.c.) is greater for fluorene than for diphenyl (1·86 c.c.). This means that as a result of conjugation a fluorene monoanil will have an even greater polarisability than calculated. The increase in dispersion forces which will accompany the higher molecular polarisability must be sufficiently great to counteract the increase in molecular separation in the fluorene monoanils, and to result in more stable mesophases. It is of interest that the increase in average transition temperature from diphenyl to fluorene anils is greater for the nematic phase (24·5°) than for the smectic phase (10·6°). In the fluorene monoanil, the greater conjugation, which is likely to extend from one end of the molecule to the other, will probably increase the intermolecular terminal cohesions more than it will the lateral cohesions, and so may be responsible for the greater increase in the nematic stability. A similar argument has been used to explain the higher stability of the nematic phases in the dianils of benzidine than in those of *p*-phenylenediamine.

The most noticeable effect in a comparison of the monoanils from diphenyl and fluorenone is the marked reduction in smectic stability (82·1°) of the fluorenone derivatives. This reduction may be accounted for by the considerably increased breadth (1·59—1·6 Å) of the fluorenone molecule. Acting to counterbalance this effect, however, is the dipole moment (2·75 μ) of the carbonyl group. Consideration of the conjugation in a fluorenone monoanil would suggest that the contribution from a structure involving $>\overset{+}{C}-\bar{O}$ will be greatly reduced through inclusion of structures such as (III), in which the positive charge is no longer localised on the carbonyl-carbon atom.



(III)

The conjugation will have two complementary effects, that of decreasing the influence of the dipole moment on lateral cohesions, since the overall dipole in a canonical structure such as (III) is no longer directed across the molecule, and of increasing the terminal cohesions, again because of the direction of the dipole. In these terms it is possible to offer a qualitative explanation of the large reduction in stability of the smectic phase and of the much smaller reduction in stability of the nematic phase on passing from a diphenyl to a fluorenone monoanil.

TABLE 6. 2 : 7-*Di*-(p-n-*alkoxybenzylideneamino*)*fluorenes*.

	Temp. of transition to				Temp. of transition to		
Alkyl	smectic	nematic	isotropic	Alkyl	smectic	nematic	isotropic
Methyl	—	263°	>380°	Octyl	166°	298°	325·7°
Ethyl	—	213	>380	Nonyl	147	296·5	315·8
Propyl	213°	214·5	373	Decyl	144	294·3	306
Butyl	182	256·5	366·5	Dodecyl	136	286·5	288·5
Pentyl	179	285	353·7	Hexadecyl	123	—	264
Hexyl	176	295·5	345·8	Octadecyl	130	—	255·3
Heptyl	164	298·5	336·5				

TABLE 7. 2 : 7-*Di*-(p-n-*alkoxybenzylideneamino*)*fluorenones*.

	Temp. of transition to				Temp. of transition to		
Alkyl	smectic	nematic	isotropic	Alkyl	smectic	nematic	isotropic
Methyl	—	250°	>350°	Octyl	150°	253·5°	302°
Ethyl	—	187	>350	Nonyl	141·5	261	291·8
Propyl	—	200	>350	Decyl	136·5	263	282
Butyl	—	179·5	>350	Dodecyl	130	261	266
Pentyl	175·5°	189	333·5	Hexadecyl	119·5	—	244·5
Hexyl	166	217·5	328	Octadecyl	121·5	—	240
Heptyl	157·5	237	311·5				

In an attempt to verify this order of decreasing thermal stability for derivatives of fluorene, diphenyl, and fluorenone, the dianils from 2 : 7-diamino-fluorene and -fluorenone were examined and compared with the analogous diphenyl dianils (Table 5). The results (m. p.s and mesomorphic transition temperatures) are summarised in Tables 6 and 7.

Decomposition and sublimation of the phases of the first two members in Table 6 and of the first four members in Table 7 prevented the measurement of the nematic–isotropic

transition temperatures. The four series of dianils (cf. Tables 4—7) exhibit the normal behaviour of diphenyl and fluorene anils when their smectic–nematic and mesomorphic–isotropic transition temperatures are plotted against the number of carbon atoms in the *n*-alkyl chain.

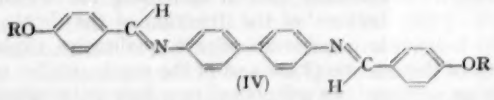
In order to compare the diphenyl, fluorene, and fluorenone dianils, the smectic–nematic and nematic–isotropic transition temperatures of the heptyl—decyl ethers have been averaged, and these averages give an indication of the relative stabilities of the smectic and the nematic phases in the three series. The summarised results are annexed, the stability decreases also being indicated.

Average transition temp. (C_7—C_{10})	Dianils from diphenyl		fluorene		fluorenone
Smectic–nematic	313°	16·2°	296·8°	43·2°	253·6°
Nematic–isotropic	345	24°	321	24·2°	296·8

These values indicate a partial inversion in the order of decreasing mesomorphic thermal stability found for the monoanils. The order now becomes diphenyl, fluorene, fluorenone.

Unless free rotation about bonds is assumed, the dianils from benzidine, 2 : 7-diaminofluorene, and 2 : 7-diaminofluorenone will probably adopt a *trans*-configuration—the probable shape of a diphenyl dianil is shown in (IV).

The molecule is essentially linear, although the major axis of the molecule, through the 4 : 4′-positions, lies parallel to, but not coincident with, the axes of the *p*-alkoxybenzylidene groups. The distortion in fluorene and fluorenone will alter this shape, so that the dianils will be planar but saucer-shaped, and it may well be that this deviation from linearity prevents the close packing in the mesophase which is possible in the diphenyl dianils. Any attempt to assess these differences in packing by use of models would be highly hypothetical. A more open packing would prevent the greater polarisability and conjugation of fluorene



(IV)

from producing the more stable mesophases. That packing of the molecules is probably important in the fluorene dianils is shown by the greater reduction in nematic stability (24°) than in smectic stability (16·2°) on passing from a diphenyl to a fluorene anil. This may be explained in terms of the ability of saucer-shaped molecules to pack more closely in a smectic phase than in a nematic phase, where the molecules must be sufficiently separated to slide over one another in a direction parallel to the inter-ring bond in the fluorene nucleus.

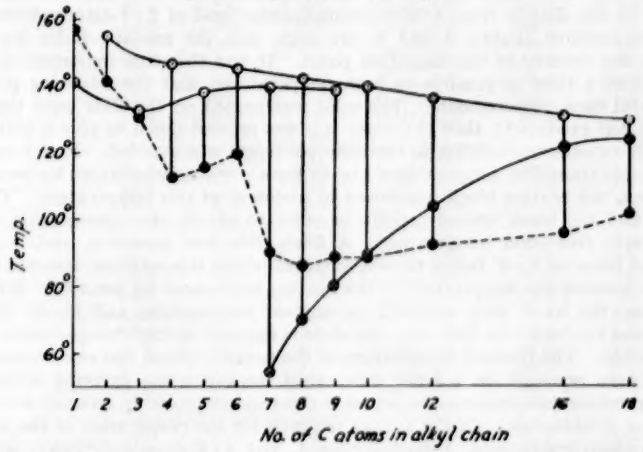
Comparison of the fluorene dianils with those from fluorenone illustrates a further thermal stability decrease in both phase types, the smectic stability decrease being the more marked. The identical packing of the molecules in the smectic phases will involve a greater separation in the fluorenone dianils as a result of the increase in breadth caused by the carbonyl group. This will not only reduce the smectic stability, but will also involve a smaller increase in separation of the molecules on passing from a fluorenone smectic phase to the nematic phase. These effects explain the smaller nematic stability decrease from a fluorene to a fluorenone dianil. As with the monoanils the decrease in stability on passing from a diphenyl to a fluorenone dianil is greater for the smectic phase (59·4°) than for the nematic phase (48·2°). The difference between the two stability changes is, however, much less. Conjugation in the fluorenone dianil can yield two canonical structures in which the carbonyl-oxygen atom is negatively charged, but in which the positive charge will be localised on opposite ends of the molecule. Such canonical structures will contribute equally to a hybrid in which the dipole will act across the molecule. The latter will reduce the extent of the smectic stability decrease as obtained for the monoanils, while at the same time decreasing the stability of the nematic phase of the fluorenone dianils.

The qualitative considerations, arising from the behaviour of the anils, cannot yet be discussed in more quantitative terms.

Finally, there is the anomalous behaviour of the mesomorphic transition temperatures when they are plotted against the number of carbon atoms in the *n*-alkyl chain of the fluorenone monoanils. The Figure illustrates the effects and shows the departure from the usual smooth, falling curves on which nematic–isotropic transition points lie, and the persistence of nematic phases at the end of the series so that the smectic–nematic curve no longer becomes coincident with the upper transition point curve.

The disappearance of nematic behaviour in the higher homologues of a series has been interpreted (Gray, Hartley, and Brynmor Jones, *J.*, 1955, 1412) in terms of the gradual increase in lateral cohesions and in smectic stability with the gradual decrease in terminal cohesions and nematic stability as the *n*-alkyl chain length grows. The result will be a stage at which the smectic phase passes direct to the isotropic liquid, because of reduction in the cohesion between the terminal groups of individual smectic layers, and before any sliding of the molecules in one layer can take place to give a nematic phase. It has already been noted that the lateral cohesions in the fluorenone monoanils are very weak, as illustrated by the large stability decrease from a diphenyl monoanil. The terminal cohesions

2-p-n-*Alkoxybenzylideneaminofluorenones.*



Temp. of transition to (○) *isotropic,* (●) *mesomorphic or isotropic, and* (⊗) *smectic phase.*

will therefore be relatively much stronger than the lateral cohesions (cf. the large nematic phase lengths in the fluorenone monoanils). Consequently, the stage at which terminal cohesion weakness or nematic instability causes the smectic phase to pass direct to the isotropic liquid may well be delayed to longer chain lengths, with the result that nematic properties may persist in the dodecyl, hexadecyl, and octadecyl ethers.

It is more difficult to explain the curious shape of the first part of the nematic–isotropic curves, but the relative differences between the terminal and lateral cohesions may also cause this effect. At the beginning of the series, where the terminal cohesions are at their strongest, and the lateral cohesions are presumably relatively weak, the trend of the curves from methyl to propyl, and from ethyl to butyl may be determined solely by the former of these effects. As the chain length increases, the lateral cohesions increase, and will supplement the terminal cohesions. This may conceivably explain the rise in the curve from propyl to pentyl to heptyl, and the levelling off from butyl to hexyl. After the hexyl and heptyl ethers, the two curves fall normally, presumably because the increasing lateral cohesions can no longer counterbalance the decreasing terminal cohesions. The difference between this series and other series examined therefore appears to arise from the small relative contribution of lateral cohesions to the stability of the nematic phases of the first four members.

When this graph was first produced, the presence of impurities in the fluorenone monoanils was suspected, but the behaviour of several samples prepared and purified by different methods confirmed the results and eliminated the possibility of contamination.

Experimental

M.p.s are corrected.

Determination of Transition Temperatures.—These temperatures (solid–smectic and nematic, smectic–nematic, and smectic and nematic–isotropic) were determined in an electrically heated microscope block (Gray, *Nature*, **1953**, **172**, 1137). All transitions between mesophases and those from the isotropic liquid to the mesophase were reversible at the same temperature. In general, the nematic phases appeared from the isotropic liquid in spherical droplets which coalesced to give homogeneous plane structures containing varying numbers of threads. In the anils which exhibit no nematic properties, the appearance of the smectic phase from the isotropic liquid was apparent by the formation of well-defined bâtonnets. All the smectic phases consisted of focal-conic groups, which were frequently large and very well defined. In most cases the usual accuracy of measurement (±0·25°) of the transition temperatures in the microscope heating block can be claimed. The only exceptions were the nematic–isotropic transition temperatures of the dianils from 4 : 4′-diaminodiphenyl and of 2 : 7-diaminofluorene. These transition temperatures (Tables 5 and 6) are high, and the nematic melts are inclined to decompose in the vicinity of the transition point. It was therefore important to expose the slide for as short a time as possible to high temperatures, and the following procedure was adopted to fulfil these requirements. The solid was heated on the slide until the nematic or smectic phase was produced; then the cover slip was pressed down to give a uniform section. In this way an unnecessary heating to the isotropic liquid was avoided. Rough values for the nematic–isotropic transition temperatures having been previously obtained by using an electric m. p. apparatus, the heating block was raised to within 5° of this temperature. The cold slide was inserted and the block heated rapidly in order to obtain the approximate value of the nematic–isotropic transition temperature. A fresh slide was mounted, and, with the temperature of the block at 1—2° below the expected transition temperature, inserted in the block. The cold slide lowered the temperature of the heating instrument by some 8°. With a gradual rate of heating, the block soon regained its original temperature, and finally the transition temperature was reached. In this way, the slide is exposed to high temperatures for as short a time as possible. The reversal temperature to the nematic phase was also measured, and the observations were repeated on a fresh slide, until measurements agreeing within 0·5° were obtained. Transition temperatures measured in this way are probably accurate to within ±1·0°.

Preparation of Materials.—Of the amines required for the preparation of the anils, purified samples of *p*-phenylenediamine, 4-aminodiphenyl, and 4 : 4′-diaminodiphenyl were available commercially, and modified methods of preparing 2-aminofluorene and 2-aminofluorenone have recently been described (Gray, Hartley, and Ibbotson, *J.*, 1955, 2686). 2 : 7-Diaminofluorene and 2 : 7-diaminofluorenone were prepared according to the methods of Morgan and Thomason (*J.*, **1926**, 2691) and Barker and Barker (*J.*, **1954**, 870) respectively. The preparation of the *p*-*n*-alkoxybenzaldehydes has already been described (Gray and Brynmor Jones, *J.*, **1954**, 1467).

The anils of the above amines were prepared by dissolving the mono- or di-amine (0·2 g.) in absolute ethyl alcohol (25 ml.), and adding a 10% molar excess of *p*-alkoxybenzaldehyde, with a few drops of glacial acetic acid as catalyst. In general, the reaction was complete after 15 minutes' warming on the water-bath, but, for the dianils from 2 : 7-diaminofluorenone, it was necessary to increase the amount of alcohol to 75 ml. and to heat the reaction mixture for 1 hr., to overcome the low solubility of the diamine. In all cases, the reaction mixtures were cooled, and the products collected, washed with ethyl alcohol, and crystallised from ethyl alcohol and benzene until the m. p.s were constant. When the solubility in alcohol was very low, the anils were digested with boiling alcohol and the suspensions filtered before the products were crystallised to constant m. p. from benzene.

As indicated in the discussion, the 2-*p*-alkoxybenzylideneaminofluorenones exhibit a peculiar behaviour of the nematic–isotropic transition point curves. To ascertain whether the anils were pure, methods of preparation and purification, other than those described in the general method above, were attempted. Condensations were carried out in twice the volume of absolute ethyl alcohol, in glacial acetic acid, in benzene, and in 2-ethoxyethanol. In the last of these,

condensation occurred, but the product was difficult to purify, whilst in benzene no reaction took place. The products obtained from the first three of these solvents were purified, but showed no change in the original m. p.s or mesomorphic transition temperatures. Rigid purification of the *p*-alkoxybenzaldehydes was likewise ineffective in altering the constants. Other methods of purification were also investigated, but chromatography on activated alumina, with carbon tetrachloride as solvent, appeared to decompose the anils. Vacuum-sublimation and repeated crystallisation from alcohol, benzene, and light petroleum, did not alter the constants, which were therefore finally accepted as the correct values.

The analytical figures for all the *anils* are summarised in the following Tables.

Alkyl	Found (%) C	H	N	Formula	Required (%) C	H	N
4-p-n-*Alkoxybenzylideneaminodiphenyls.*							
Me	83·6	6·1	4·7	$C_{20}H_{17}ON$	83·6	6·0	4·9
Et	83·6	6·7	4·6	$C_{21}H_{19}ON$	83·7	6·4	4·6
Pr^n	83·8	6·7	4·6	$C_{22}H_{21}ON$	83·8	6·7	4·6
Bu^n	83·7	7·0	4·1	$C_{23}H_{23}ON$	83·9	7·0	4·2
C_5H_{11}	83·9	7·3	4·3	$C_{24}H_{25}ON$	84·0	7·4	4·1
C_6H_{13}	83·7	7·4	3·7	$C_{25}H_{27}ON$	84·0	7·6	3·9
C_7H_{15}	83·8	7·6	3·7	$C_{26}H_{29}ON$	84·1	7·9	3·8
C_8H_{17}	84·0	8·0	3·4	$C_{27}H_{31}ON$	84·2	8·1	3·6
C_9H_{19}	84·2	8·2	3·3	$C_{28}H_{33}ON$	84·2	8·3	3·5
$C_{10}H_{21}$	84·0	8·5	3·5	$C_{29}H_{35}ON$	84·3	8·5	3·4
$C_{12}H_{25}$	84·1	8·9	3·1	$C_{31}H_{39}ON$	84·4	8·9	3·2
$C_{16}H_{33}$	84·3	9·6	2·6	$C_{35}H_{47}ON$	84·5	9·5	2·8
$C_{18}H_{37}$	84·7	9·7	2·5	$C_{37}H_{51}ON$	84·6	9·7	2·6
2-p-n-*Alkoxybenzylideneaminofluorenes.*							
Me	84·2	5·7	4·5	$C_{21}H_{17}ON$	84·2	5·7	4·7
Et	84·3	5·9	4·6	$C_{22}H_{19}ON$	84·3	6·1	4·5
Pr^n	84·3	6·5	4·3	$C_{23}H_{21}ON$	84·4	6·4	4·3
Bu^n	84·2	6·8	4·2	$C_{24}H_{23}ON$	84·4	6·7	4·1
C_5H_{11}	84·4	6·9	4·0	$C_{25}H_{25}ON$	84·5	7·0	3·9
C_6H_{13}	84·6	7·3	3·8	$C_{26}H_{27}ON$	84·5	7·3	3·8
C_7H_{15}	84·7	7·5	3·8	$C_{27}H_{29}ON$	84·6	7·6	3·7
C_8H_{17}	84·5	7·9	3·7	$C_{28}H_{31}ON$	84·6	7·8	3·5
C_9H_{19}	84·6	8·1	3·5	$C_{29}H_{33}ON$	84·7	8·0	3·4
$C_{10}H_{21}$	84·7	8·2	3·4	$C_{30}H_{35}ON$	84·7	8·2	3·3
$C_{12}H_{25}$	84·8	8·6	3·2	$C_{32}H_{39}ON$	84·8	8·6	3·1
$C_{16}H_{33}$	84·7	9·2	3·0	$C_{36}H_{47}ON$	84·9	9·2	2·8
$C_{18}H_{37}$	85·0	9·4	2·5	$C_{38}H_{51}ON$	84·9	9·5	2·6
2-p-n-*Alkoxybenzylideneaminofluorenones.*							
Me	80·2	4·9	4·6	$C_{21}H_{15}O_2N$	80·5	4·8	4·5
Et	80·8	5·1	4·2	$C_{22}H_{17}O_2N$	80·7	5·2	4·3
Pr^n	81·1	5·7	4·1	$C_{23}H_{19}O_2N$	80·9	5·6	4·1
Bu^n	81·2	5·7	4·1	$C_{24}H_{21}O_2N$	81·1	6·0	3·9
C_5H_{11}	81·2	6·1	3·9	$C_{25}H_{23}O_2N$	81·3	6·3	3·8
C_6H_{13}	81·4	6·4	3·6	$C_{26}H_{25}O_2N$	81·4	6·6	3·6
C_7H_{15}	81·7	6·7	3·7	$C_{27}H_{27}O_2N$	81·6	6·8	3·5
C_8H_{17}	81·8	7·2	3·5	$C_{28}H_{29}O_2N$	81·7	7·1	3·4
C_9H_{19}	81·6	7·3	3·4	$C_{29}H_{31}O_2N$	81·8	7·3	3·3
$C_{10}H_{21}$	82·0	7·4	3·1	$C_{30}H_{33}O_2N$	81·9	7·6	3·2
$C_{12}H_{25}$	82·4	7·8	2·9	$C_{32}H_{37}O_2N$	82·2	8·0	3·0
$C_{16}H_{33}$	82·7	8·7	2·6	$C_{36}H_{45}O_2N$	82·5	8·7	2·7
$C_{18}H_{37}$	82·8	8·8	2·5	$C_{38}H_{49}O_2N$	82·7	8·9	2·5
4 : 4′-*Di*-(p-n-*alkoxybenzylideneamino*)*diphenyls.*							
Me	80·2	5·9	6·5	$C_{26}H_{24}O_2N_2$	80·0	5·7	6·7
Et	80·5	6·2	6·3	$C_{30}H_{28}O_2N_2$	80·4	6·3	6·3
Pr^n	80·6	6·6	5·8	$C_{32}H_{32}O_2N_2$	80·7	6·7	5·9
Bu^n	80·8	7·0	5·6	$C_{34}H_{36}O_2N_2$	81·0	7·1	5·6
C_5H_{11}	81·2	7·4	5·3	$C_{36}H_{40}O_2N_2$	81·2	7·5	5·3
C_6H_{13}	81·4	7·6	5·4	$C_{38}H_{44}O_2N_2$	81·4	7·9	5·0
C_7H_{15}	81·4	8·2	5·0	$C_{40}H_{48}O_2N_2$	81·6	8·2	4·8
C_8H_{17}	81·6	8·4	4·8	$C_{42}H_{52}O_2N_2$	81·8	8·4	4·6
C_9H_{19}	81·6	8·6	4·3	$C_{44}H_{56}O_2N_2$	82·0	8·7	4·4
$C_{10}H_{21}$	82·0	9·0	4·2	$C_{46}H_{60}O_2N_2$	82·1	8·9	4·2
$C_{12}H_{25}$	82·5	9·6	3·7	$C_{50}H_{68}O_2N_2$	82·4	9·3	3·8
$C_{16}H_{33}$	83·0	9·8	3·4	$C_{58}H_{84}O_2N_2$	82·7	10·0	3·3
$C_{18}H_{37}$	83·0	10·2	3·0	$C_{62}H_{92}O_2N_2$	83·0	10·3	3·1

Alkyl	Found (%) C	H	N	Formula	Required (%) C	H	N
				2 : 7-*Di*-(p-n-*alkoxybenzylideneamino*)*fluorenes*.			
Me	80·4	5·4	6·7	$C_{39}H_{34}O_2N_2$	80·6	5·6	6·5
Et	80·8	6·1	6·2	$C_{41}H_{38}O_2N_2$	80·8	6·1	6·1
Pr^n	81·2	6·4	5·8	$C_{43}H_{42}O_2N_2$	81·1	6·6	5·7
Bu^n	81·6	6·8	5·3	$C_{45}H_{46}O_2N_2$	81·4	7·0	5·4
C_5H_{11}	81·4	7·3	5·3	$C_{47}H_{50}O_2N_2$	81·6	7·3	5·2
C_6H_{13}	81·8	7·9	4·8	$C_{49}H_{54}O_2N_2$	81·8	7·7	4·9
C_7H_{15}	82·3	7·8	4·7	$C_{51}H_{58}O_2N_2$	82·0	8·0	4·7
C_8H_{17}	82·2	8·2	4·4	$C_{53}H_{62}O_2N_2$	82·2	8·3	4·5
C_9H_{19}	82·3	8·6	4·2	$C_{55}H_{66}O_2N_2$	83·2	8·5	4·3
$C_{10}H_{21}$	82·4	8·7	4·1	$C_{57}H_{70}O_2N_2$	82·5	8·8	4·1
$C_{12}H_{25}$	82·4	9·1	3·6	$C_{61}H_{78}O_2N_2$	82·7	9·2	3·8
$C_{14}H_{29}$	82·8	9·8	3·3	$C_{65}H_{86}O_2N_2$	83·1	9·8	3·3
$C_{16}H_{33}$	83·5	9·9	3·0	$C_{69}H_{94}O_2N_2$	83·3	10·1	3·1
				2 : 7-*Di*-(p-n-*alkoxybenzylideneamino*)*fluorenones*.			
Me	77·8	4·9	6·5	$C_{39}H_{32}O_3N_2$	78·0	4·9	6·3
Et	78·5	5·6	5·7	$C_{41}H_{36}O_3N_2$	78·5	5·5	5·9
Pr^n	78·8	5·8	5·6	$C_{43}H_{40}O_3N_2$	78·9	6·0	5·6
Bu^n	79·0	6·5	5·4	$C_{45}H_{44}O_3N_2$	79·2	6·4	5·3
C_5H_{11}	79·3	6·7	4·8	$C_{47}H_{48}O_3N_2$	79·6	6·8	5·0
C_6H_{13}	79·6	7·1	4·7	$C_{49}H_{52}O_3N_2$	79·9	7·2	4·8
C_7H_{15}	79·8	7·5	4·7	$C_{51}H_{56}O_3N_2$	80·1	7·5	4·6
C_8H_{17}	80·6	7·9	4·2	$C_{53}H_{60}O_3N_2$	80·4	7·8	4·4
C_9H_{19}	80·4	7·8	4·0	$C_{55}H_{64}O_3N_2$	80·6	8·0	4·2
$C_{10}H_{21}$	80·7	8·4	4·1	$C_{57}H_{68}O_3N_2$	80·8	8·3	4·0
$C_{12}H_{25}$	80·7	8·7	3·8	$C_{61}H_{76}O_3N_2$	81·2	8·8	3·7
$C_{14}H_{29}$	81·3	9·5	3·0	$C_{65}H_{84}O_3N_2$	81·7	9·5	3·2
$C_{16}H_{33}$	82·1	9·7	2·7	$C_{69}H_{92}O_3N_2$	82·0	9·8	3·0
				p-n-*Alkoxybenzylideneanilines* (*m. p. in parentheses*).			
Me (56°)	79·5	6·3	6·5	$C_{14}H_{13}ON$	79·6	6·2	6·6
C_7H_{15} (58)	81·2	8·6	4·8	$C_{21}H_{27}ON$	81·4	8·5	4·8
$C_{12}H_{25}$ (73)	82·1	9·6	3·7	$C_{25}H_{35}ON$	82·2	9·6	3·8
$C_{14}H_{29}$ (76·5)	82·6	10·2	3·2	$C_{29}H_{43}ON$	82·7	10·2	3·3
$C_{16}H_{33}$ (84)	82·7	10·4	3·0	$C_{31}H_{47}ON$	82·9	10·5	3·1
				NN′-*Di*-(p-n-*alkoxybenzylidene*)-p-*phenylenediamines*.			
Me	76·5	5·9	7·9	$C_{32}H_{30}O_2N_2$	76·7	5·8	8·1
Et	77·1	6·4	7·5	$C_{34}H_{34}O_2N_2$	77·4	6·5	7·5
Pr^n	78·1	7·2	6·9	$C_{36}H_{38}O_2N_2$	78·0	7·0	7·0
Bu^n	78·8	7·4	6·8	$C_{38}H_{42}O_2N_2$	78·5	7·5	6·5
C_5H_{11}	79·1	8·0	5·8	$C_{30}H_{36}O_2N_2$	78·9	7·9	6·1
C_6H_{13}	79·2	8·5	6·0	$C_{32}H_{40}O_2N_2$	79·3	8·3	5·8
C_7H_{15}	79·8	8·4	5·2	$C_{34}H_{44}O_2N_2$	79·7	8·6	5·5
C_8H_{17}	80·2	8·9	5·0	$C_{36}H_{48}O_2N_2$	80·0	8·9	5·2
C_9H_{19}	80·1	9·3	5·0	$C_{38}H_{52}O_2N_2$	80·3	9·2	4·9
$C_{10}H_{21}$	80·8	9·6	4·9	$C_{40}H_{56}O_2N_2$	80·5	9·4	4·7
$C_{12}H_{25}$	81·1	9·8	4·2	$C_{44}H_{64}O_2N_2$	81·0	9·8	4·3
$C_{14}H_{29}$	81·9	10·4	3·7	$C_{48}H_{72}O_2N_2$	81·7	10·5	3·7
$C_{16}H_{33}$	82·2	10·7	3·2	$C_{52}H_{80}O_2N_2$	82·0	10·7	3·4

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THE UNIVERSITY, HULL.

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Further Experiments relating to the Condensation of Substituted Indoles with Hexane-2 : 5-dione.

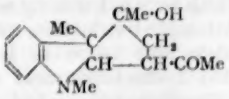
By D. A. Cockerill, Sir Robert Robinson, and J. E. Saxton.

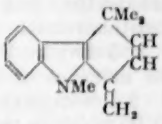
[Reprint Order No. 6548.]

The condensation of 1 : 3-dimethylindole with hexane-2 : 5-dione (Robinson and Saxton, *J.*, 1953, 2596) followed by vigorous treatment of the product with concentrated hydrochloric acid afforded a substance, $C_{16}H_{17}N$, tentatively formulated on the basis of a carbazole skeleton. Attempted synthesis has proved unsuccessful and the failure to find an exocyclic methylene group casts doubt on the suggestion made in 1953. An alternative is that the compound is a derivative of *cyclo*heptane.

The condensation of 1 : 2-dimethylindole and hexane-2 : 5-dione with the help of hydrogen chloride led to the formation of 2 : 5-di-(1′ : 2′-dimethyl-3′-indolyl)hexa-2 : 4-diene. A similar (2 : 1) condensation was realised on using 1 : 2-dimethylindole and 2 : 5-dimethoxytetrahydrofuran.

1 : 3-Dimethylindole and hexane-2 : 5-dione condense in aqueous-alcoholic hydrogen chloride with formation of a substance, $C_{16}H_{21}O_2N$, which is very probably (I) (*loc. cit.*). The action on this of concentrated hydrochloric acid at 100° afforded a neutral compound,

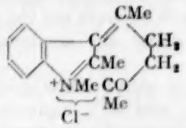
(I) 

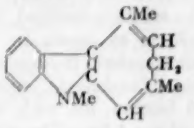
 (II)

$C_{16}H_{17}N$ (deeply coloured picrate), thought to be (II) though the possibility of *cyclo*heptatriene formulations was also contemplated.

The dubieties in regard to the structure (II), arising from its infrared spectrum, are much increased by our failure to obtain any trace of formaldehyde after ozonisation.

There is no loss of carbon in the reaction (I ⟶ II) and therefore (since $C_{16}H_{17}N$ is certainly an aromatic indole derivative) the 3-methyl group (indole numbering) has probably migrated. The alternative is to break the *cyclo*pentane ring of (I) between the two CMe groups and this greatly increases the difficulty of representing the loss of both oxygen atoms in an acceptable manner. If, however, we assume the intermediate (III) as the result of a migration of methyl from position 3 to position 2 of the indole nucleus, the further change to (IV) is a natural one, and this structure (IV) now becomes our preferred working hypothesis for the constitution of $C_{16}H_{17}N$. There are two obvious variations of (IV) produced by a shift of one or other of the double bonds.

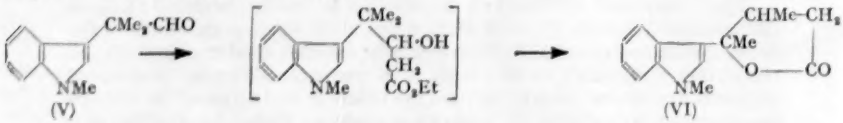
(III) 

 (IV)

This formula agrees with the 2 *C*-Me groups found in $C_{16}H_{17}N$ and its hexahydro-derivative (no sufficient increase for C:CH_2 ⟶ :CHMe), as well as the indole character and extended conjugation of the substance (ultraviolet spectrum).

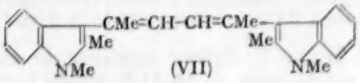
An attempted synthesis of (II) was on the following lines. α-3-Indolyl*iso*butyric acid was prepared by the noteworthy method of Erdtman and Jonsonn (*Acta Chem. Scand.*, 1954, **8**, 119) which involves the condensation of indole with acetone and chloroform in presence of alkali. The ester of this acid has been *N*-methylated by Potts and Saxton (*J.*, 1954, 2642) and we have now reduced this derivative to 2-(1-methyl-3-indolyl)-2-methylpropan-1-ol by means of lithium aluminium hydride. The corresponding aldehyde (V) (prepared by the Oppenauer method, using *p*-benzoquinone and aluminium *tert.*-butoxide) gave a variety of complex condensation products with acetone. This aldehyde

did not condense with malonic acid under the conditions of the Doebner reaction and it was inactive towards ethyl acetoacetate in presence of piperidine. It condensed, however, with ethyl bromoacetate and zinc under Reformatzky conditions to a product which was not isolated but was converted by hot formic acid into a γ-lactone (infrared band). The formation of a γ-lactone requires the migration of a methyl group and the most probable interpretation leads to the structure (VI).



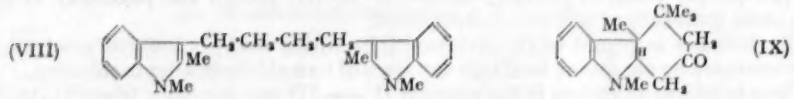
(V) (VI)

The condensation of 1 : 2-dimethylindole with hexane-2 : 5-dione might have provided an intermediate for synthesis of the heptatriene derivative (IV) but it proceeded (2 : 1), in alcoholic solution containing hydrogen chloride, with formation of the bisindole (VII).



(VII)

On catalytic reduction this product afforded a tetrahydro-derivative, the ultraviolet absorption spectrum and the colour reactions of which were in harmony with its formulation as a 1 : 2 : 3-trisubstituted indole derivative. Attempted reduction with tin and hydrochloric acid gave 2 : 3-dihydro-1 : 2-dimethylindole and fission to 1 : 2-dimethylindole occurred under the influence of hot concentrated hydrochloric acid alone. Analogous condensation of 1 : 2-dimethylindole with 2 : 5-dimethoxytetrahydrofuran gave a lower bis-homologue of (VII) which on catalytic reduction yielded the compound (VIII).



The condensation of 1 : 3-dimethylindole with mesityl oxide in aqueous-alcoholic hydrogen chloride parallels the case of methyl*cyclo*hexenone previously described (Robinson and Saxton, *loc. cit.*). The properties of the product are consistent with the structure (IX).

Experimental

Action of Ozone on the Substance, $C_{16}H_{17}N$.—The indole derivative (0·24 g.) was ozonised in carbon tetrachloride solution (30 c.c.) and absorption ceased after 40 min. The issuing gas was passed through a saturated aqueous solution of dimedone but there was no precipitate and the dimedone was all recovered on evaporation. The solid ozonide was added to dilute sulphuric acid (50 c.c.) and the solution distilled, but neither the exit vapours nor the aqueous condensate contained formaldehyde as shown by the failure to obtain any condensation product with dimedone or 2 : 4-dinitrophenylhydrazine.

α-(1-*Methyl*-3-*indolyl*)*iso*butyric *Acid*.—A mixture of ethyl 1-methyl-3-indolyl*iso*butyrate (3·8 g.) (Potts and Saxton, *loc. cit.*), ethanol (50 c.c.), and 40% aqueous sodium hydroxide (10 c.c.) was refluxed for 4 hr. The *acid*, obtained in the usual way, crystallised from ethanol in colourless plates (2·5 g.), m. p. 181° (Found : C, 71·6; H, 7·0; N, 6·5; NMe, 7·7. $C_{13}H_{15}O_2N$ requires C, 71·9; H, 6·9; N, 6·5; NMe, 13·4%).

2-(1-*Methyl*-3-*indolyl*)-2-*methylpropan*-1-*ol*.—A solution of ethyl α-(1-methyl-3-indolyl)-*iso*butyrate (4·8 g.) in ether (100 c.c.) was added during 15 min. to a stirred suspension of lithium aluminium hydride (10 g.) in ether (100 c.c.), and the whole refluxed for 30 min. After cooling, ethanol, water, and dilute hydrochloric acid were added. The residue, after evaporation of the dried, ethereal layer, crystallised from light petroleum (b. p. 60—80°). 2-(1-*Methyl*-3-*indolyl*)-2-*methylpropan*-1-*ol* (3·4 g.) was obtained as long, colourless prisms, m. p. 86—87° (Found : C, 76·7; H, 8·35; N, 7·2. $C_{13}H_{17}ON$ requires C, 76·85; H, 8·4; N, 6·9%). The *picrate* crystallised from benzene as orange-red needles, m. p. 106—108° (Found : C, 52·9; H, 4·9; N, 12·7. $C_{19}H_{20}O_8N_4$ requires C, 52·8; N, 4·6; N, 13·0%).

α-(1-*Methyl*-3-*indolyl*)*iso*butyraldehyde (V).—2-(1-Methyl-3-indolyl)-2-methylpropan-1-ol was

unaffected by boiling with aluminium *tert.*-butoxide in acetone, and by chromic acid in *tert.*-butyl alcohol.

A mixture of the alcohol (2 g.), *p*-benzoquinone (4 g.), aluminium *tert.*-butoxide (5 g.), and dry benzene (50 c.c.) was refluxed for 1 hr. The cooled solution was filtered, the solid was washed well with ether, and the combined organic extracts were washed with dilute sulphuric acid and then with aqueous sodium hydroxide until the aqueous extracts were colourless. At this stage emulsions were troublesome and the alkali was added in portions of 25 c.c. and the liquids merely swirled until most of the quinone had been removed. The ether–benzene solution was then dried, the solvent removed, and the residue crystallised from light petroleum (b. p. 40—60°). α-(1-*Methyl*-3-*indolyl*)*isobutyraldehyde* (1·3 g.) was obtained as colourless prisms, m. p. 69—70° (Found : C, 77·8; H, 7·4; N, 7·2. $C_{13}H_{15}ON$ requires C, 77·6; H, 7·4; N, 7·0%). The infrared spectrum shows the presence of an unconjugated carbonyl group (band at 5·84 μ). The *semicarbazone* crystallised from ethanol as colourless rhombs, m. p. 208—209° (Found : C, 65·2; H, 7·1; N, 21·4. $C_{14}H_{18}ON_4$ requires C, 65·1; H, 7·0; N, 21·7%).

β-*Methyl*-γ-(1-*methyl*-3-*indolyl*)-γ-*valerolactone* (VI).—A mixture of methylindolyl*iso*butyraldehyde (3·7 g.), ethyl bromoacetate (4 c.c.), zinc wool (1·5 g.), mercuric chloride (0·1 g.), and benzene (50 c.c.) was heated until a reaction started, which was then allowed to proceed. When the initial reaction had subsided, ethyl bromoacetate (4 c.c.) was added, and the mixture boiled for 5 hr. Acetic acid and water were added after cooling, and the aqueous layer was extracted with ether. The combined organic extracts were washed with dilute aqueous ammonia until the aqueous layer was colourless. The ether–benzene layer was then dried, and the solvent removed. The residue was dissolved in formic acid (25 c.c.) and the solution heated on the steam-bath for 5 hr. The solvent was removed *in vacuo*, the residue dissolved in ether, the ethereal solution washed with dilute aqueous sodium carbonate solution, then dried, and the solvent removed. The residue was dissolved in benzene, and filtered through a column of activated alumina (80 g.). The combined eluates yielded the *lactone* (1·5 g.), which crystallised from benzene as colourless prisms, m. p. 147° (Found : C, 73·8; 74·4, H, 7·1, 6·9; N, 5·9. $C_{15}H_{17}O_2N$ requires C, 74·1; H, 7·0; N, 5·8%). The infrared spectrum shows no peak at 2·87 μ (OH), but a pronounced peak at 5·68 μ (unconjugated γ-lactone CO). When the crude Reformatzky product was treated with iodine (0·2 g.) in boiling toluene, the lactone was again obtained (undepressed mixed m. p. and identical infrared spectrum).

The uncrystallisable oil obtained by filtration of the crude Reformatzky reaction product through alumina showed a hydroxyl band at 2·87 μ, and an ester band at 5·83 μ. The lactone was unchanged when boiled for 6 hr. with red phosphorus and hydrogen iodide in acetic acid.

Methyl γ-*Hydroxy*-β-*methyl*-γ-(1-*methyl*-3-*indolyl*)-n-*valerate*.—A solution of the above lactone (1 g.) in ethanol (10 c.c.) along with aqueous sodium hydroxide (5 c.c. of 20%) was boiled for 3 hr. and then cooled overnight. *Sodium* γ-*hydroxy*-β-*methyl*-γ-(1-*methyl*-3-*indolyl*)-*valerate* then separated and was recrystallised from acetone–benzene, and so obtained as colourless prisms, m. p. 217°. After drying at 100° for 4 hr., it had m. p. 228—230° (Found : C, 62·0; H, 6·5; N, 5·1; Na, 7·8. $C_{15}H_{18}O_3NNa,\frac{1}{2}H_2O$ requires C, 61·7; H, 6·5; N, 4·8; Na, 7·9%).

The sodium salt (1 g.) was dissolved in acetone (20 c.c.) and methyl iodide (5 c.c.), and the solution boiled for 4 hr. The solvent was removed, the residual oil dissolved in ether, and the solution filtered from sodium iodide, dried, and evaporated. The residue crystallised slowly and recrystallised from light petroleum (b. p. 60—80°). The methyl ester (0·5 g.) was obtained as colourless prisms, m. p. 73—75° (Found : C, 70·2; H, 7·5; N, 5·1. $C_{16}H_{21}O_3N$ requires C, 69·8; H, 7·6; N, 5·1%). The infrared spectrum shows a hydroxyl band at 2·87, and an ester band at 5·82 μ.

γ-*Hydroxy*-β-*methyl*-γ-(1-*methyl*-3-*indolyl*)-n-*valeric Acid*.—The sodium salt (1 g.) was dissolved in the minimum of cold water, and excess of dilute hydrochloric acid added. The precipitated *acid* was collected, washed well with cold water, and dissolved in the minimum of cold acetone. Gradual dilution of this solution with cold water gave colourless needles (0·59 g.), which softened and dehydrated above 59° to a pasty mass, which clarified above 140° (Found : C, 65·0; H, 7·6; N, 5·1. $C_{16}H_{19}O_3N,H_2O$ requires C, 64·5; H, 7·5; N, 5·0%). Slow crystallisation of the hydroxy-acid from acetone–benzene yields the lactone, m. p. and mixed m. p. 147°.

Distillation of the methyl ester of the hydroxy-acid at 160—170°/0·07 mm. (bath) gave a mixture of lactone and unchanged hydroxy-ester.

The lactone was also obtained on boiling a solution of the hydroxy-ester in xylene containing iodine for 2 hr.

2 : 5-*Di*-(1 : 2-*dimethyl*-3-*indolyl*)*hexa*-2 : 4-*diene* (VII).—A slow stream of hydrogen chloride was passed through a solution of hexane-2 : 5-dione (2·5 g.) and 1 : 2-dimethylindole

(5 g.) in ethanol (20 c.c.), at 0°, until no further solid was precipitated (about 20 min.). The product was collected, washed with ethanol, and crystallised from pyridine. The hexadiene (1·5 g., 23%) was obtained as colourless, hexagonal plates, m. p. 235°, raised to 242° by two further crystallisations from the same solvent. The substance was also obtained as long, colourless prisms, m. p. 270°. A mixture of the two forms gave m. p. 228—232° so that they may be geometrical stereoisomers. The ultraviolet spectrum showed maxima at 2300 and 2900 Å as usually observed with indole derivatives; the extinction coefficients at these peaks were however much lower than the corresponding values for simple indoles.

When the di-(dimethylindolyl)hexadiene (7 g.) was heated for 1 hr. on the steam-bath with concentrated hydrochloric acid (80 c.c.), the only isolable product was 1 : 2-dimethylindole (3·9 g.), m. p. 55° [picrate, red needles (from benzene), m. p. and mixed m. p. 121°].

2 : 3-*Dihydro*-1 : 2-*dimethylindole*.—(*A*) A mixture of 1 : 2-dimethylindole (4 g.), ethanol (50 c.c.), concentrated hydrochloric acid (50 c.c.), and granulated tin (15 g.) was refluxed for 7 hr. The basic product (3·5 g.) was obtained as a colourless oil, b. p. 103—104°/18 mm., affording a *picrate*, yellow plates (from ethanol), m. p. 131—133° (decomp.) (Found : C, 51·1; H, 4·2; N, 15·1. $C_{10}H_{13}N,C_6H_3O_7N_3$ requires C, 51·1; H, 4·3; N, 14·9%).

(*B*) A mixture of the di-(dimethylindolyl)hexadiene (6 g.), concentrated hydrochloric acid (40 c.c.), and tin (15 g.) was boiled for 3 hr. The base isolated in the known manner was purified by distillation. 2 : 3-Dihydro-1 : 2-dimethylindole (4·2 g.) was collected as a colourless oil, b. p. 101—102°/17 mm., n_D^{23} 1·5394 (Found : C, 81·2; H, 9·1; N, 9·5. Calc. for $C_{10}H_{13}N$: C, 81·6; H, 8·8; N, 9·6%). The picrate crystallised from ethanol as yellow plates, m. p. and mixed m. p. 131—133° (Found : C, 51·1, 51·4; H, 4·2, 4·4; N, 15·2%).

2 : 5-*Di*-(1 : 3-*dimethyl*-3-*indolyl*)*hexane*.—The hexadiene (1·8 g.) in pure dioxan (100 c.c.) was hydrogenated in the presence of Raney nickel at 130°/100 atm. for 7 hr. The solution was filtered, and the solvent removed under reduced pressure. The residue was triturated with ethanol, and crystallised twice from the same solvent. 2 : 5-*Di*-(1 : 2-*dimethyl*-3-*indolyl*)*hexane* (1·5 g.) was obtained as colourless prisms, m. p. 157—160° [Found : C, 84·2; H, 8·4; N, 7·3%; *M* (cryoscopic in camphor), 301. $C_{26}H_{32}N_2$ requires C, 83·9; H, 8·6; N, 7·5%; *M*, 372]. This substance gives a blue-grey colour when warmed with Ehrlich's reagent; on cooling the colour disappears, an alternation which can be repeated *ad libitum*. The *dipicrate* was prepared in benzene solution, and crystallised from ethanol as brown needles, m. p. 191—192° (Found : C, 55·1; H, 4·9; N, 13·4. $C_{26}H_{32}N_2,2C_6H_3O_7N_3$ requires C, 54·9; H, 4·9; N, 13·5%). This tetrahydro-derivative of (VII) showed normal indole absorption in the ultraviolet region.

An attempted reduction in dioxan using Adams catalyst at the room temperature and pressure did not succeed.

Attempted Reaction of 2 : 5-*Di*-(1 : 2-*dimethyl*-3-*indolyl*)*hexa*-2 : 4-*diene with Maleic Anhydride*.—A solution of the hexadiene (2 g.), maleic anhydride (1·5 g.), and trichloroacetic acid (0·01 g.) in xylene (100 c.c.) was refluxed for 7 hr. The solvent was removed by distillation under reduced pressure, and the residue warmed with dilute sodium hydroxide solution. The solid was collected and crystallised from pyridine. Unchanged hexadiene was recovered as colourless plates, m. p. and mixed m. p. 241°.

Other examples of the non-reactivity of inner units of long conjugated systems have been reported (cf. Weizmann, Bergmann, and Haskelberg, *J.*, 1939, 391; Dilthey, Schommer, and Trösken, *Ber.*, 1933, **66**, 1627).

1 : 4-*Di*-(1 : 2-*dimethyl*-3-*indolyl*)*butadiene*.—Hydrogen chloride was slowly passed through an ice-cooled mixture of 1 : 2-dimethylindole (2 g.), tetrahydro-2 : 5-dimethoxyfuran (4 g.), ethanol (5 c.c.), and water (0·5 c.c.). The stirred mixture was kept at 0° until crystallisation was complete; then the solid was collected, washed well with ethanol, and crystallised twice from pyridine. 1 : 4-*Di*-(1 : 2-*dimethyl*-3-*indolyl*)*butadiene* (0·5 g., 21%) was obtained as colourless, hexagonal plates, m. p. 292—294°, with softening above 275° (Found : C, 84·6; H, 7·3; N, 8·5; *C*-Me, 6·5. $C_{24}H_{24}N_2$ requires C, 84·7; H, 7·1; N, 8·3; 2*C*-Me, 8·8%). The properties of this substance closely resembled those of the hexadiene derivative (VII) described above.

1 : 4-*Di*-(1 : 2-*dimethyl*-3-*indolyl*)*butane* (VIII).—The butadiene (1·4 g.) in pure dioxan (100 c.c.) was hydrogenated in the presence of Raney nickel at 150°/100 atm. for 8 hr. After filtration the solvent was removed under reduced pressure and the residue triturated with light petroleum (b. p. 40—60°) and crystallised twice from benzene. 1 : 4-*Di*-(1 : 2-*dimethyl*-3-*indolyl*)*butane* (1·0 g.) was obtained as colourless rhombs, m. p. 174—176° (Found : C, 84·0; H, 7·9; N, 8·1. $C_{24}H_{28}N_2$ requires C, 83·7; H, 8·1; N, 8·1%). This substance gave a pale pink colour on warming with Ehrlich's reagent; the colour disappeared on cooling, and the usual alternation was possible.

1 : 2 : 3 : 4 : 10 : 11-*Hexahydro*-4 : 4 : 9 : 11-*tetramethyl*-2-*oxocarbazole* (IX).—A solution of 1 : 3-dimethylindole (2·7 g.) in ethanol (10 c.c.) and water (2 c.c.) was saturated with hydrogen chloride, mesityl oxide (3 g.) added, and the mixture kept for 2 hr. Water was added, and the solution extracted with ether. The ethereal solution was dried and evaporated, and the residue triturated with benzene until crystallisation was complete. The solid was collected and recrystallised from aqueous ethanol. The *tetramethyl-2-oxocarbazole* (2·5 g.) was obtained as colourless needles, m. p. 96—97° (Found: C, 78·8; H, 8·7. $C_{16}H_{21}ON$ requires C, 79·0; H, 8·6%).

This weak base closely resembles 1 : 4-ethylene-1 : 2 : 3 : 4 : 10 : 11-hexahydro-4 : 9 : 11-trimethyl-2-oxocarbazole (Robinson and Saxton, *loc. cit.*) in its properties. It gives a deep red colour with weakly acid ferric chloride, an indicator azo-compound with diazobenzenesulphonic acid, and a deep carmine-red colour with a mixture of sulphuric and nitric acid.

Succinoylbis-1 : 2-*dimethylindole*.—An intimate mixture of 1 : 2-dimethylindole (5 g.), succinic anhydride (1·8 g.), and powdered zinc chloride (2·5 g.) was heated on a steam-bath for 2 hr. The liquid became deep red and viscous, and on cooling set to a red glass. Water (60 c.c.) was added and the mixture boiled for 5 min., cooled, and kept overnight in the refrigerator. The deep red solid was collected, triturated with ethanol, and crystallised from 2-methoxyethanol. The product (2 g., 31%) was obtained as elongated, colourless prisms, m. p. 215—224° (decomp.) dependent on the rate of heating (Found: C, 77·1; H, 6·7. $C_{24}H_{24}O_2N_2$ requires C, 77·4; H, 6·5%). This *substance* gives a deep reddish-magenta colour with mineral acids. The infrared spectrum shows pronounced peaks at 5·87 and 6·11 μ. This suggests an unsymmetrical constitution or that the substance is a mixture. One of the carbonyl groups is doubtless in position 3 of an indole nucleus because 3-acetyl-1 : 2-dimethylindole (Borsche and Groth, *Annalen*, 1941, **549**, 238, give m. p. 103—104° for this substance but, after three crystallisations from benzene and drying at 80°/15 mm., we find m. p. 110°) has been examined for comparison and found to show a strong band at 6·08 μ. The band at 5·87 μ indicates a carbonyl group attached to an aromatic nucleus.

The reduction of the succinoylbisdimethylindole gave several products which could not be identified.

This work was carried out during the tenure of an I.C.I. Fellowship (J. E. S.).

DYSON PERRINS LABORATORY, OXFORD UNIVERSITY. [*Received, June 27th*, 1955.]

Hydroxylation of Pregn-16-en-20-ones. Part I. Permanganate Oxidation of Pregn-16-en-20-ones.

By GEORGE COOLEY, BERNARD ELLIS, FRANK HARTLEY, and VLADIMIR PETROW.

[Reprint Order No. 6502.]

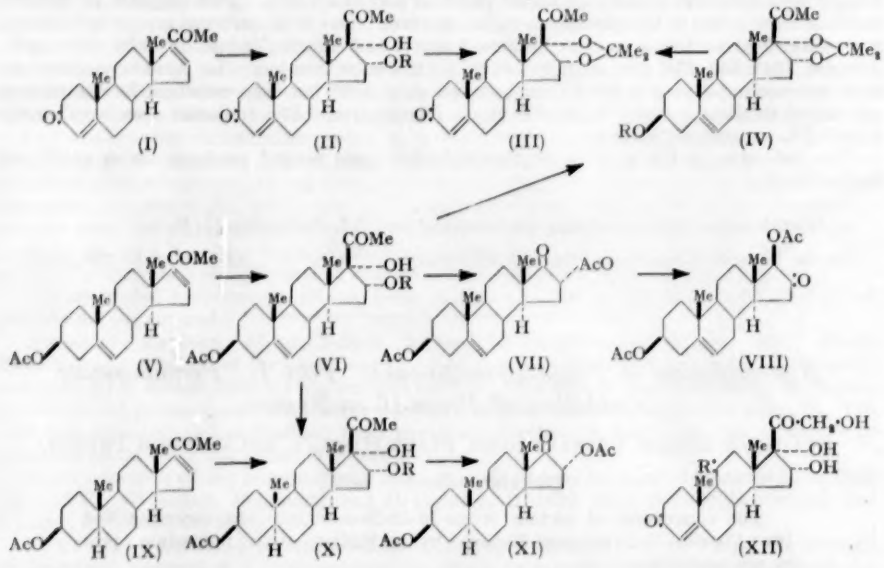
The conversion of certain pregn-16-en-20-ones into the corresponding 16α : 17α-dihydroxypregnan-20-ones by oxidation with potassium permanganate is described.

IN December, 1953, studies were initiated on the preparation of 16α-hydroxy-"Compound-S" (XII; R = H_2) and 16α-hydroxycortisone (XII; R = O), which were required for biological study. No information was available at the time on methods for building up the 16α : 17α-dihydroxyketol grouping. We consequently explored possible routes and first oxidised selected pregn-16-en-20-ones with potassium permanganate and with osmic acid. Unfortunately, both reagents gave rise not to one but to several series of hydroxy-compounds which, in addition, proved unexpectedly labile. At this stage a publication appeared by Inhoffen, Blomeyer, and Bruckner (*Chem. Ber.*, 1954, **87**, 593) (cf. B.P. 715,402, Løvens Kemiske Fabrik) covering some common ground. The views expressed therein on structural problems are largely at variance with conclusions since reached by ourselves and recorded in the present series. Their experimental results, in contrast, proved complementary to our own and provided valuable data for the elucidation

of structural issues. Our work is presented in three Parts, each dealing with a separate aspect of the problem.

Oxidation of 3β-acetoxypregna-5 : 16-dien-20-one (V) with potassium permanganate at 0° in acetone containing a limited quantity of acetic acid (cf. Part III) gave a product, $C_{23}H_{34}O_5$, which failed to show the ultraviolet absorption of an aβ-unsaturated ketone. The constitution 3β-acetoxy-16α : 17α-dihydroxypregn-5-en-20-one (VI; R = H) is assigned to this compound on the basis of the following transformations.

Reaction between this product and acetone containing a trace of hydrochloric acid gave the *iso*propylidene derivative (IV; R = Ac), the formation of which established the *cis*-configuration of the newly introduced α-glycol group (see Butenandt and Schäffer, *Z. Naturforsch.*, **1946**, **1**, 82, and especially Huffman *et al.*, *J. Amer. Chem. Soc.*, **1944**, **66**, 150; **1947**, **69**, **1835**). Acetylation of the triol monoacetate (VI; R = H) in pyridine furnished 3β : 16α-diacetoxy-17α-hydroxypregn-5-en-20-one (VI; R = Ac), which passed on catalytic hydrogenation into 3β : 16α-diacetoxy-17α-hydroxy*allo*pregnan-20-one (X; R = Ac), additionally obtained by oxidising 3β-acetoxy*allo*pregn-16-en-20-one (IX) with potassium permanganate, followed by acetylation of the resulting 3β-acetoxy-16α : 17α-dihydroxy*allo*pregnan-20-one (X; R = H).



Careful oxidation of the diol (X; R = Ac) with chromium trioxide in acetic acid led to 3β : 16α-diacetoxyandrostan-17-one (XI), a compound recently obtained by another method by Leeds, Fukushima, and Gallagher (*ibid.*, 1954, **76**, 2943), who have provided a rigorous proof of its structure. This observation establishes the 5-membered character of ring D in (X) (cf. Part II below), as well as the α-configuration of the 16-hydroxyl group. Further evidence on these points follows from the observation that the compound (VI; R = Ac) differs from the isomeric 3β : 16β-diacetoxy-17α-hydroxypregn-5-en-20-one recently obtained by Heusler and Wettstein (*Ber.*, 1954, **87**, 1301) by catalysed acetolysis of 3β-acetoxy-16α : 17α-epoxypregn-5-en-20-one. That the two compounds are, in fact, epimeric at $C_{(16)}$ has now been established by their conversion into the hitherto unknown 3β : 16α-diacetoxy- (VII) and 3β : 16β-diacetoxy-androst-5-en-17-one, respectively, by reduction of the 20-keto-groups with sodium borohydride, followed by oxidative cleavage of the

resulting (not isolated) 17 : 20-glycols with periodic acid. When either the diacetate (VII) or its $C_{(16)}$-epimer was treated with dilute methanolic potassium hydroxide at room temperature, a ketol rearrangement to the more stable 3β : 17β-dihydroxyandrost-5-en-16-one [isolated as the 3β : 17β-diacetate (VIII)] occurred in analogy to the formation of 3β : 17β-dihydroxyandrostan-16-one from the saturated diacetate (XI) under similar experimental conditions (cf. Leeds *et al.*, *loc. cit.*).

Oxidation of pregna-4 : 16-diene-3 : 20-dione (I) with potassium permanganate gave a hydroxylated derivative, $C_{21}H_{30}O_4$, with an absorption maximum at 240 mμ (ε 16,600) indicating the presence of the original 3-oxo-Δ^4-group and the absence of the 20-oxo-Δ^{16}-residue which had presumably been involved in the hydroxylation reaction. We consequently assign to this product the constitution 16α : 17α-dihydroxypregn-4-ene-3 : 20-dione (II; R = H) and in confirmation thereof find that it gives a monoacetate (II; R = Ac) on acetylation and an *iso*propylidene derivative identical with 16α : 17α-*iso*propylidenedioxypregn-4-ene-3 : 20-dione (III) formed by Oppenauer oxidation of the alcohol (IV; R = H) obtained from its acetate (IV; R = Ac) (see above) by alkaline hydrolysis.

Experimental

In this and the following two papers, optical rotations were measured in $CHCl_3$ in a 1-dm. tube, and ultraviolet absorption spectra (in propan-2-ol) were kindly determined by Mr. M. Davies, B.Sc.

3β-*Acetoxy*-16α : 17α-*dihydroxypregn*-5-*en*-20-*one* (VI; R = H).—A solution of potassium permanganate (18 g.) in aqueous acetone (1·05 l. of 85%) was added during 45 min. to a stirred ice-cooled solution of 3β-acetoxypregna-5 : 16-dien-20-one (40 g.) in a mixture of acetone (1·2 l.) and acetic acid (8 ml.). After treatment with sulphur dioxide, the pale yellow solution was decanted from inorganic salts, and most of the solvents were removed *in vacuo*. The product was extracted into ether (*ca.* 2 l.) and the extract washed with water, aqueous sodium hydrogen carbonate, and water and then dried. Concentration to 400 ml. gave crystals (14·7 g.), m. p. 140—170°, a further quantity of material (13·8 g.) of m. p. 170—185° being obtained by concentration of the mother-liquor to half its bulk. The combined products were crystallised several times from methanol to give 3β-*acetoxy*-16α : 17α-*dihydroxypregn*-5-*en*-20-*one* (8 g.), dense plates, m. p. 210—212°, $[\alpha]_D^{20}$ −65° (*c*, 1·37) (Found : C, 71·0; H, 9·0. $C_{23}H_{34}O_5$ requires C, 70·7; H, 8·8%).

Acetylation in pyridine for 30 min. at 100° gave 3β : 16α-*diacetoxy*-17α-*hydroxypregn*-5-*en*-20-*one*, silky needles (from methanol), m. p. 214—215°, $[\alpha]_D^{20}$ −74° (*c*, 1·02) (Found : C, 69·4; H, 8·45. $C_{25}H_{36}O_6$ requires C, 69·4; H, 8·4%).

3β-*Acetoxy*-16α : 17α-iso*propylidenedioxypregn*-5-*en*-20-*one* (IV; R = Ac).—3β-Acetoxy-16α : 17α-dihydroxypregn-5-en-20-one (350 mg.) in hot acetone (20 ml.) was treated with 2 drops of concentrated hydrochloric acid. The solution was gently boiled for 2 min., then set aside overnight, and the product obtained on dilution with water purified from aqueous methanol. The iso*propylidene* derivative (300 mg.) formed needles, m. p. 175°, $[\alpha]_D^{21}$ −18° (*c*, 0·75) (Found : C, 72·9; H, 8·8. $C_{26}H_{38}O_5$ requires C, 72·5; H, 8·9%).

3β : 16α-*Diacetoxy*-17α-*hydroxy*allo*pregnan*-20-*one* (X; R = Ac).—3β : 16α-Diacetoxy-17α-hydroxypregn-5-en-20-one (810 mg.) in ethyl acetate (35 ml.) containing prereduced Adams platinum catalyst (50 mg.) and a trace of perchloric acid was hydrogenated at room temperature and pressure until 1·1 equivs. of hydrogen were absorbed. The product was purified from aqueous methanol, giving needles (430 mg.) of 3β : 16α-*diacetoxy*-17α-*hydroxy*allo*pregnan*-20-*one*, m. p. 159°, $[\alpha]_D^{21}$ −16° (*c*, 0·54) (Found : C, 69·6; H, 9·0. $C_{25}H_{38}O_6$ requires C, 69·1; H, 8·8%).

3β-*Acetoxy*-16α : 17α-*dihydroxy*allo*pregnan*-20-*one* (X; R = H).—A stirred ice-cooled solution of 3β-acetoxy*allo*pregn-16-en-20-one (3·5 g.) in acetone (100 ml.) was treated with a solution of potassium permanganate (1·4 g.) in aqueous acetone (140 ml. of 90%) dropwise during 1 hr. After decolorisation with sulphur dioxide, the mixture was decanted from inorganic salts and concentrated *in vacuo* until solids began to separate. The product (1·75 g.), m. p. 183°, was purified from methanol to give lustrous plates of 3β-*acetoxy*-16α : 17α-*dihydroxy*allo*pregnan*-20-*one*, m. p. 222°, $[\alpha]_D^{21}$ +3° (*c*, 0·76) (Found : C, 70·3; H, 9·3. $C_{23}H_{36}O_5$ requires C, 70·4; H, 9·25%).

Acetylation in pyridine gave the 16α-acetoxy-derivative, m. p. 159°, not depressed on admixture with a specimen prepared by the method described above.

3β : 16α-*Diacetoxyandrostan-20-one* (XI).—3β : 16α-Diacetoxy-17α-hydroxy*allo*pregnan-20-one (200 mg.) in acetic acid (5 ml.) was treated for 21 hr. at room temperature with chromium trioxide (100 mg.) in acetic acid (5 ml. of 98%). The neutral fraction of the oxidation product was crystallised from aqueous methanol, giving 3β : 16α-diacetoxyandrostan-20-one (50 mg.), needles, m. p. 183—184°, $[\alpha]_D^{22}$ +55° (*c*, 0·5) (Found : C, 70·5; H, 8·8. Calc. for $C_{23}H_{34}O_5$: C, 70·7; H, 8·8%). Leeds *et al.* (*loc. cit.*) give m. p. 184—185°, $[\alpha]_D^{23}$ +57·1°.

3β : 16α-*Diacetoxyandrost-5-en-17-one* (VII).—To a suspension of 3β : 16α-diacetoxy-17α-hydroxypregn-5-en-20-one (1·65 g.) in methanol (100 ml.) was added a solution of sodium borohydride (500 mg.) in methanol. A few drops of acetic acid were added after 10 min.; then the mixture was poured into water and the product isolated with ether. The solids obtained were dissolved in methanol (60 ml.) and treated for 18 hr. with periodic acid (1·6 g.) in water (15 ml.). The product, isolated with ether, was purified from aqueous ethanol to give 3β : 16α-*diacetoxyandrost-5-en-17-one* (700 mg.), needles, m. p. 167—168°, $[\alpha]_D^{20}$ −18° (*c*, 0·97) (Found : C, 70·7; H, 8·4. $C_{23}H_{32}O_5$ requires C, 71·1; H, 8·3%).

3β : 16β-*Diacetoxyandrost-5-en-17-one.*—Sodium borohydride (300 mg.) was added to a suspension of 3β : 16β-diacetoxy-17α-hydroxypregn-5-en-20-one (900 mg.) in methanol (50 ml.). After 10 min., the clear solution was acidified with acetic acid and diluted with water, and the precipitate collected by filtration. The air-dried material in methanol (60 ml.) was treated for 18 hr. with periodic acid (1 g.) in water (10 ml.). Dilution with water gave a crystalline solid which was purified from aqueous methanol. 3β : 16β-*Diacetoxyandrost-5-en-17-one* separated in bright needles, m. p. 180—181° (sinters at 165°), $[\alpha]_D^{22}$ +6° (*c*, 0·82) (Found : C, 71·1; H, 8·1. $C_{23}H_{32}O_5$ requires C, 71·1; H, 8·3%).

3β : 17β-*Diacetoxyandrost-5-en-16-one* (VIII).—The foregoing compound (150 mg.) in methanolic 0·04N-potassium hydroxide (75 ml.) was kept at room temperature for 18 hr. After dilution with water, the product was isolated with methylene dichloride–ether, and acetylated in pyridine in the usual manner. 3β : 17β-Diacetoxyandrost-5-en-16-one separated from aqueous methanol in flat needles, m. p. and mixed m. p. 124—125°.

The same compound was obtained by similar treatment of 3β : 16α-diacetoxyandrost-5-en-17-one.

16α : 17α-*Dihydroxypregn-4-ene-3* : 20-*dione* (II; R = H).—Potassium permanganate (8 g.) in aqueous acetone (230 ml. of 85%) was added during 1 hr. to a stirred ice-cooled solution of pregna-4 : 16-diene-3 : 20-dione (20 g.) in a mixture of acetone (600 ml.) and acetic acid (4 ml.). After treatment with sulphur dioxide, the solution was decanted from inorganic salts and concentrated *in vacuo* to a small volume. The product was extracted with ether, and the extract was washed with water, aqueous sodium hydrogen carbonate, and water, and dried. Concentration to 150 ml. gave dense crystals (7·3 g.), m. p. 209—220°, purified by extraction with a small volume of hot acetone followed by crystallisation from ethanol–methylene dichloride. 16α : 17α-*Dihydroxypregn-4-ene-3* : 20-*dione* formed needles, m. p. 225°, $[\alpha]_D^{22}$ +95° (*c*, 0·81) (Found : C, 72·3; H, 8·75. $C_{21}H_{30}O_4$ requires C, 72·8; H, 8·7%).

On acetylation in pyridine, 16α-*acetoxy*-17α-*hydroxypregn-4-ene-3* : 20-*dione* was obtained, needles (from aqueous methanol), m. p. 176—177°, $[\alpha]_D^{20}$ +49° (*c*, 1·25) (Found : C, 67·8, 68·7; H, 8·4, 8·3. $C_{23}H_{32}O_5,H_2O$ requires C, 68·1; H, 8·2%).

16α : 17α-iso*Propylidenedioxypregn-4-ene-3* : 20-*dione* (III).—(*a*) 3β-Acetoxy-16α : 17α-*iso*-propylidenedioxypregn-5-en-20-one (3 g.) in methanolic 2·5% potassium hydroxide1(40 ml.) was refluxed for 30 min. Careful addition of water gave needles (2·5 g.), m. p. 2 7—218° (Found : C, 74·2; H, 9·3. $C_{24}H_{36}O_4$ requires C, 74·2; H, 9·3%). A solution of thisproduct (2·3 g.) in toluene (80 ml.) and *cyclo*hexanone (20 ml.) was distilled until 25 ml. of distillate had been collected. Following the addition of aluminium *iso*propoxide in toluene (18 ml. of 25% solution), the mixture was refluxed for 30 min., cooled and extracted with concentrated aqueous, Rochelle salt solution. Removal of solvents by steam-distillation gave crystals (1·7 g.), m. p. 190—200°. Purified from aqueous ethanol, 16α : 17α-iso*propylidenedioxypregn-4-ene-3* : 20-*dione* formed needles, m. p. 210°, $[\alpha]_D^{20}$ +137° (*c*, 0·7) (Found : C, 74·2; H, 9·0. $C_{24}H_{34}O_4$ requires C, 74·6; H, 8·9%).

(*b*) 16α : 17α-Dihydroxypregn-4-ene-3 : 20-dione (350 mg.) in hot acetone (20 ml.) was treated with 2 drops of concentrated hydrochloric acid. Next morning, the solution was poured into water and the precipitate crystallised from aqueous ethanol, to give the *iso*propylidene derivative (330 mg.), needles, identical with a sample prepared by method (*a*) in m. p., mixed m. p., and optical rotation.

The compound was recovered substantially unchanged after treatment with aqueous acetic acid (70%) for 2·5 hr. at 100°.

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*Hydroxylation of Pregn-16-en-20-ones. Part II.** D-*Homo-derivatives derived from* 16α : 17α-*Dihydroxypregnan-20-ones.*

By GEORGE COOLEY, BERNARD ELLIS, FRANK HARTLEY, and VLADIMIR PETROW.

[Reprint Order No. 6503.]

3β-Acetoxypregna-5 : 16-dien-20-one (I) adds osmic acid in the presence of pyridine to give a complex (II), which may be converted into the dihydroxy-ketones (IV; R = H), (V; R = R′ = H), and (III; R = H). The last two compounds are transformed by methanolic potassium hydroxide into 3β : 17-dihydroxy-17*a*-methyl-D-homoandrosta-5 : 17-dien-16-one (VI; R = H), which forms a quinoxaline derivative and yields the dicarboxylic acid (IX) on oxidation with alkaline hydrogen peroxide.

Pregna-4 : 16-diene-3 : 20-dione (XI) may similarly be converted into the compounds (XII), (X) and (XIII).

ADDITION of osmium tetroxide to 3β-acetoxypregna-5 : 16-dien-20-one (I) in ether containing a small proportion of pyridine was followed by rapid separation of a light-brown crystalline steroid–osmium tetroxide–pyridine complex. The normal 16α : 17α-cyclic osmate structure (II) is assigned to this compound on the basis of its conversion in low yield into 3β : 16α-diacetoxy-17α-hydroxypregn-5-en-20-one (IV; R = Ac) by very brief treatment with aqueous-alkaline mannitol, followed by acetylation of the product. Reductive hydrolysis of the osmate (II) with aqueous-ethanolic sodium sulphite led to a compound *A*, $C_{23}H_{34}O_5$, and a deacetylated compound *B*, $C_{21}H_{32}O_4$.

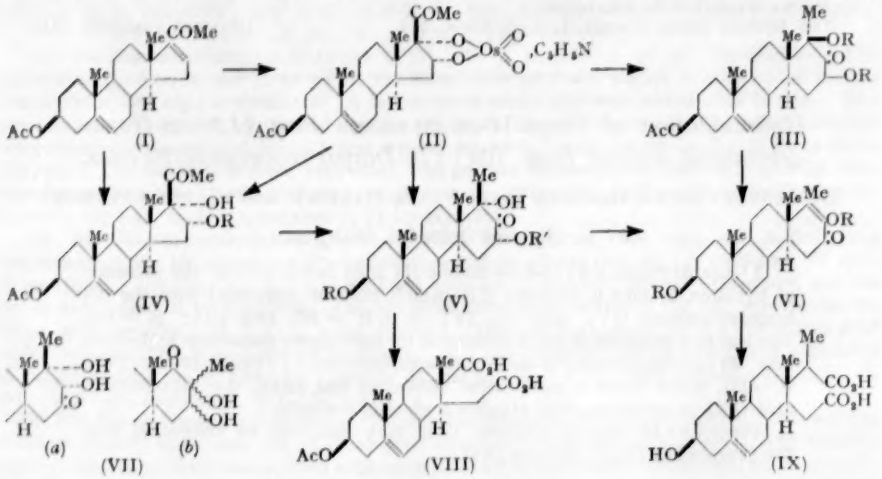
Structure of Compound A.—The first formulation, 3β-acetoxy-16α : 17α-dihydroxypregn-5-en-20-one (IV; R = H), for this product was discarded when the material proved to be different from authentic (IV) prepared as described in Part I (preceding paper). We therefore assumed that reaction of the osmate (II) with hot aqueous-ethanolic sodium sulphite had led to a labile intermediate such as (IV), which then underwent alkali-promoted rearrangement to structures of the D-homo-type (cf. Turner, *J. Amer. Chem. Soc.*, 1953, **75**, 3484). Both 17*a*-hydroxy-17*a*-methyl-D-homo- (VII*a*) and 17-hydroxy-17-methyl-D-homo- (VII*b*) structures were possible from theoretical considerations. Both were, however, excluded by the alkaline dehydrations (see below) leading to compounds (VI) and thence (IX).

Acetylation of compound *A* with acetic anhydride in pyridine at *room* temperature gave unexpectedly a triacetate, indicating (i) the presence of a less hindered, equatorial (β) 17*a*-hydroxyl group and (ii) a system of the type ·CMe(OH)·CO·C(OH)< in which acetylation of the tertiary hydroxyl group would be facilitated by a mechanism involving acyl migration. Examination of models showed that such a situation exists only in that structure in which the 16- and the 17*a*-hydroxyl group are both equatorial (β) and hence in the same plane as the 17-keto-group. The constitution 3β-acetoxy-16β : 17*a*β-dihydroxy-17*a*α-methyl-D-homoandrost-5-en-17-one (III; R = H) is consequently assigned to compound *A*. In support we find that the material (i) shows infrared absorption (kindly determined by Dr. L. J. Bellamy) consistent with a structure in which a carbonyl group in a six-membered ring is doubly bonded to hydrogen atoms furnished by two adjacent

* Part I, preceding paper.

hydroxyl groups, (ii) does not form an *iso*propylidene derivative, and (iii) does not show ultraviolet absorption characteristic of αβ-unsaturated ketones.

Heusler and Wettstein (*Chem. Ber.*, 1954, **87**, 1301) recently described a high-melting triolone prepared by reaction between 3β : 16β-diacetoxy-17α-hydroxypregn-5-en-20-one and potassium hydroxide, potassium carbonate, or alcoholic hydrochloric acid. They



recognised the product as a D-homo-steroid but did not assign a precise constitution to it. Acetylation with hot acetic anhydride gave a diacetate, whilst pyridine–acetic anhydride at 80° furnished a triacetate. Comparison of the physical constants reported for the triester with those of our 3β : 16β-17*a*β-triacetoxy-17*a*α-methyl-D-homoandrost-5-en-17-one (III; R = Ac) leaves little doubt that the two compounds are identical. The parent triolone must therefore be regarded as 3β : 16β : 17*a*β-trihydroxy-17*a*α-methyl-D-homoandrost-5-en-17-one and the diacetate derived from it as the 3β : 16β-diester.

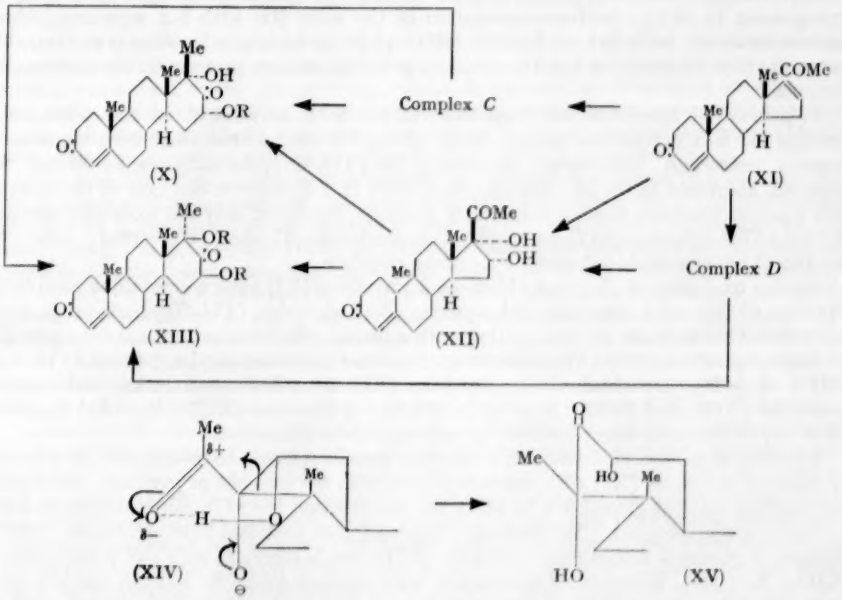
Structure of Compound B.—In contrast to compound *A*, acetylation of this triolone gave only a diacetate which differed, moreover, from the compound (IV; R = Ac). The parent compound is therefore isomeric with (III) and (IV) (free alcohols). Its constitution follows from the following evidence.

17β-Hydroxy-20-oxopregnane derivatives are known to undergo D-homo-annulation when chromatographed on to alumina showing basic, neutral, or acidic reactions, whereas 17α-hydroxy-20-oxopregnanes do not rearrange under these conditions and are also more resistant to isomerisation by alkali than are the corresponding 17β-hydroxy-epimers (cf. Turner, *loc. cit.*). In contrast, we now find that 3β-acetoxy-16α : 17α-dihydroxypregn-5-en-20-one (IV; R = H) is smoothly converted by chromatography on basic alumina into an isomeric monoacetate, which forms an *iso*propylidene derivative and passes into compound *B* diacetate an acetylation. The constitution of 3β : 16α : 17*a*α-trihydroxy-17*a*β-methyl-D-homoandrost-5-en-17-one (V; R = R′ = H) is consequently assigned to compound *B*, (i) on the reasonable assumption that the isomeric change produced by chromatography of (IV; R = H) involves normal D-homo-annulation and (ii) on the evidence of *iso*propylidene formation, which establishes the axial orientation of the *cis*-1 : 3-glycol system (cf. Sneedon and Turner, *J. Amer. Chem. Soc.*, 1953, **75**, 3500; Angyal and Macdonald, *J.*, 1952, 686). Its alternative formulation on the basis of (VII*a*) is considered less likely as (i) hot aqueous sulphite is presumably a more drastic isomerising agent than basic alumina, (ii) reductive hydrolysis and D-homo-annulation of (II) by hot sulphite gives the diolone (III; R = H) in addition to compound *B*, (iii) the compound (III) is not of type (VII*a*), but as a 16β-hydroxy-D-homo-steroid is regarded as derived from an initially formed 16α-hydroxy-D-homo-precursor by a secondary change involving an alkali-catalysed

isomerisation of a 16α(axial)-hydroxyl group to the more stable 16β(equatorial)-configuration, (iv) isomerisation of the diol (IV; R = H) by basic alumina would hardly be expected to proceed beyond the stage reached under the more drastic conditions obtaining with hot sulphite, and (v) further isomerisation of the triolone (V; R = R′ = H) would presumably lead, from analogy with (II) ⟶ (III; R = H), to the 16β(equatorial)-hydroxy-isomer and not to (VII*a*), which would represent yet a further stage in the series of changes promoted by alkali and lead ultimately to (VI; R = H) (see below). Some additional evidence bearing on this problem is presented in Part III (following paper).

Whilst the above experiments were in progress, Inhoffen, Blomeyer, and Brückner (*Chem. Ber.*, 1954, **87**, 593) reported the preparation of an osmic ester from 3β-acetoxy-5 : 6-dibromopregn-16-en-20-one, converted by hot aqueous-ethanolic sodium sulphite and zinc dust into a single, high-melting triolone considered to be 3β : 16α : 17α-trihydroxypregn-5-en-20-one (cf. IV). Acetylation gave a diacetate regarded as (IV; R = Ac). We have since repeated and confirmed these experimental findings, but are unable to accept Inhoffen, Blomeyer, and Brückner's formulations as the materials in question are identical with our D-homo-steroids (V; R = R′ = H) and (V; R = R′ = Ac).

In an attempt to confirm, by degradation, the D-homo-structure (V), the 5 : 6-dibromide of the diolone (V; R = Ac, R′ = H) was oxidised with chromium trioxide with the object of converting it, by rupture of ring D, into a keto-dicarboxylic acid (cf. Ruzicka, Gätzi, and Reichstein, *Helv. Chim. Acta*, 1939, **22**, 626; Shoppee and Prins, *ibid.*, 1943, **26**,



201). Unfortunately, oxidation proceeded beyond the required stage to give, after debromination, the dicarboxylic acid (VIII) (Kuwada, *J. Pharm. Soc. Japan*, 1936, **56**, 75).

Inhoffen, Blomeyer, and Brückner (*loc. cit.*) have previously reported that their 3β : 16α : 17α-trihydroxypregn-5-en-20-one [herein formulated as (V; R = R′ = H)] undergoes dehydration with boiling methanolic potassium hydroxide to give an enolic form of 3β-hydroxypregn-5-ene-16 : 20-dione. This interpretation of the dehydration is untenable on mechanistic grounds. In addition, it is rendered unlikely by the observation that pregnane-16 : 20-diones undergo ready alkaline hydrolysis to androstan-16-ones (Marshall and Gallagher, *J. Amer. Chem. Soc.*, 1949, **71**, 2325). We have since confirmed Inhoffen, Blomeyer, and Brückner's experimental findings and additionally obtained the

same enolic diketone from the stereoisomers (III) and (V). We assign to it the constitution 3β : 17-dihydroxy-17*a*-methyl-D-homoandrosta-5 : 17-dien-16-one (VI; R = H) on the basis of the following evidence : (*a*) its ultraviolet absorption (max. at 277 mμ), (*b*) its conversion into a diacetate (VI; R = Ac) with an absorption maximum at 245 mμ (see Dorfman, *Chem. Rev.*, 1953, **53**, 80), (*c*) its reaction with *o*-phenylenediamine to give a quinoxaline derivative, and (*d*) its oxidation with alkaline hydrogen peroxide to a dicarboxylic acid (IX) containing the same number of carbon atoms. Its formation from both (III) and (V) presumably involves alkali-catalysed rearrangement to a 17*a*-epimeric structure of type (VII*a*), followed by dehydration to the enolic diketone (VI; R = H).

Turner (*loc. cit.*) has pointed out that the rearrangement of 17-hydroxypregnan-20-ones into ketols of the D-homo-series is highly stereospecific. Thus whereas basic catalysts (aluminium *tert.*-butoxide or alumina) convert 17α- and 17β-hydroxypregnan-20-ones into 17*a*β- and 17*a*α-D-homo-ketols, respectively, Lewis acids give rise to the epimeric 17*a*α- and 17*a*β-D-homo-ketols. The results described herein are at variance with these generalisations in that D-homo-annulation of the 17α-hydroxy-compound (IV; R = H) with alumina leads stereospecifically to the 17*a*α-hydroxy(axial-OH)-steroid (V; R = Ac; R′ = H). They may, nevertheless, be reconciled with Turner's conclusions by making the legitimate assumption that orientation of the 20-carbonyl group in the transition state is governed by hydrogen bonding with the adjacent 16α-hydroxyl group. Alumina-catalysed removal of a proton from the 17-hydroxyl group of diolone (IV) and conferment of a full negative charge on oxygen will consequently lead to the transition state indicated in (XIV) and rearrangement to (XV). D-Homo-annulation of the ester (II) with hot aqueous-alcoholic sulphite, however, leads to both epimers (III) and (V) as hydrogen bonding is weakened by the competing tendency of the 16α-hydroxy-group to release protons to the surrounding medium.

Treatment of 3β-acetoxy*allo*pregn-16-en-20-one with osmic acid in the presence of pyridine led to a crystalline complex from which, by careful treatment with mannitol in aqueous potassium hydroxide, 3β-acetoxy-16α : 17α-dihydroxy*allo*pregnan-20-one was obtained, identified as the 3β : 16α-diacetate (Part I). Reductive cleavage of the complex with aqueous-ethanolic sodium sulphite, in contrast, furnished only one isolatable product, 3β : 16β : 17*a*β-trihydroxy-17*a*α-methyl-D-homoandrostan-17-one, converted into the 3β : 16β : 17*a*β-triacetate by acetic anhydride–pyridine.

Similar oxidation of pregna-4 : 16-diene-3 : 20-dione (XI) gave a crystalline complex *C*. Cleavage of this with mannitol and aqueous alkali gave 16α : 17α-dihydroxypregn-4-ene-3 : 20-dione (XII) (Part I), and heating with aqueous-ethanolic sodium sulphite provided a single product, 16β : 17*a*β-dihydroxy-17*a*α-methyl-D-homoandrost-4-ene-3 : 17-dione (XIII; R = H), also obtained directly from (XII) by D-homo-annulation under similar conditions. The diol (XIII; R = H) passed into a diacetate (XIII; R = Ac) on acetylation in pyridine and failed to form an *iso*propylidene derivative.

Inhoffen *et al.* (*loc. cit.*) describe a complex (herein referred to as complex *D*) prepared by treating the dione (XI) with osmium tetroxide in the absence of pyridine. Reduction with sodium sulphite gave a diol to which the constitution 16α : 17α-dihydroxypregn-4-ene-3 : 20-dione was assigned. We have since repeated this work and have established that the product so obtained differs from authentic (XII), but is identical with our D-homo-steroid (XIII; R = H). Reaction of complex *C* with aqueous-ethanolic sodium sulphite could be modified by the addition of zinc bromide and zinc dust : there were then formed the dihydroxy-diketone (XIII; R = H) and an isomer, the latter being also obtained directly from (XII) by alumina-promoted rearrangement. Acetylation of the new isomer gave a monoacetate, and treatment with acetone–hydrochloric acid furnished an *iso*propylidene derivative. The compound is therefore formulated as 16α : 17*a*α-dihydroxy-17*a*β-methyl-D-homoandost-4-ene-3 : 17-dione (X; R = H).

Experimental

3β-*Acetoxy*-16β : 17*a*β-*dihydroxy*-17*a*α-*methyl*-D- (III; R = H) *and* 3β : 16α : 17*a*α-*trihydroxy*-17*a*β-*methyl*-D-*homoandrost*-5-*en*-17-*one* (V; R = R′ = H).—3β-Acetoxypregna-5 : 16-dien-20-one (4 g.) in dry ether (240 ml.) containing redistilled pyridine (3·5 ml.) was treated with a

solution of osmium tetroxide (3 g.) in ether (50 ml.). Separation of light brown crystals began after 1—2 min., and was complete after 1 hr. The product was washed well with ether, giving 6·4 g. of complex. A test for nitrogen was positive.

A mixture of the foregoing complex (6·4 g.), sodium sulphite (15 g.), ethanol (110 ml.), and water (80 ml.) was refluxed for 45 min., then filtered hot, and the residue thrice washed with small portions of boiling 80% ethanol. After dilution with water, the combined filtrate and washings were extracted four times with methylene dichloride. The combined extracts were washed until neutral, dried, and concentrated to *ca.* 50 ml., whereupon crystals (810 mg.; m. p. 245—247°) separated. Purified from aqueous ethanol, 3β-*acetoxy*-16β : 17*aβ*-*dihydroxy*-17*aα*-*methyl*-D-*homoandrost*-5-*en*-17-*one* formed plates, m. p. 250°, $[\alpha]_D^{20}$ −56° (*c*, 0·57 in pyridine) (Found : C, 70·4, 70·4; H, 9·3, 9·1. $C_{23}H_{34}O_5$ requires C, 70·7; H, 8·8%).

Further concentration of the methylene dichloride mother-liquor gave a product (920 mg.; m. p. 235—245°), which, purified from aqueous ethanol, gave 3β : 16α : 17*aα*-*trihydroxy*-17*aβ*-*methyl*-D-*homoandrost*-5-*en*-17-*one*, needles, m. p. 255—256°, $[\alpha]_D^{20}$ −84° (*c*, 0·43) (Found : C, 72·0; H, 9·5. $C_{21}H_{32}O_4$ requires C, 72·4; H, 9·25%), not depressed on admixture with a specimen prepared by the method of Inhoffen *et al.* (*loc. cit.*).

Acetylation of the former product in pyridine for 24 hr. at room temperature gave the 3β : 16β : 17*aβ*-*triacetate*, needles (from aqueous ethanol), m. p. 160—161°, $[\alpha]_D^{19}$ −29° (*c*, 0·92) (Found : C, 68·5; H, 8·1. Calc. for $C_{27}H_{38}O_7$: C, 68·3; H, 8·1%) (Heusler and Wettstein, *loc. cit.*, give m. p. 157—158°, $[\alpha]_D^{22}$ −28° ± 4°).

Acetylation of the triol (V; R = R′ = H) in pyridine for 30 min. at 100° gave the 3β : 16α-*diacetate*, flat needles (from aqueous ethanol), m. p. 176—177°, $[\alpha]_D^{19}$ −99° (*c*, 0·93) (Found : C, 69·7; H, 8·4. Calc. for $C_{25}H_{36}O_6$: C, 69·4; H, 8·4%) (Inhoffen *et al.*, *loc. cit.*, give m. p. 170—171°, $[\alpha]_D^{22}$ −98·8° ± 1°).

3β : 16α-*Diacetoxy*-17α-*hydroxypregn*-5-*en*-20-*one* (IV; R = Ac).—The foregoing complex (1·1 g.), suspended in a solution of mannitol (2·0 g.) and potassium hydroxide (0·5 g.) in water (50 ml.), was heated at 100° for 10 min. The solids obtained on filtration were washed, air-dried, and acetylated in pyridine. Two crystallisations of the product from aqueous methanol gave 3β : 16α-diacetoxy-17α-hydroxypregn-5-en-20-one (50 mg.), silky needles, m. p. 214—215° not depressed on admixture with an authentic specimen (Part I, *loc. cit.*).

3β-*Acetoxy*-16α : 17*aα*-*dihydroxy*-17*aβ*-*methyl*-D-*homoandrost*-5-*en*-17-*one* (V; R = Ac, R′ = H).—A solution of 3β-acetoxy-16α : 17α-dihydroxypregn-5-en-20-one (2·6 g.) in benzene–ether (150 ml.; 1 : 1) was passed slowly through a column (12 × 1·8 cm.) of alkaline alumina. The product (2·4 g.; m. p. 185—190°) obtained on evaporation of the percolate was crystallised from ethanol to give the D-*homo*-*steroid*, flat needles, m. p. 200—201°, $[\alpha]_D^{22}$ −76° (*c*, 1·43) (Found : C, 70·4; H, 8·7. $C_{23}H_{34}O_5$ requires C, 70·7; H, 8·8%). Acetylation in pyridine gave the 3β : 16α-diacetoxy-compound, m. p. 176°, not depressed on admixture with a specimen prepared as described above. The iso*propylidene derivative* (70%), prepared by treating the diol (V; R = Ac; R′ = H) (350 mg.) in hot acetone (20 ml.) with two drops of concentrated hydrochloric acid and setting the mixture aside overnight, formed dense prisms (from *n*-hexane), m. p. 183—184°, $[\alpha]_D^{21}$ −85° (*c*, 0·87) (Found : C, 72·3; H, 9·0. $C_{26}H_{38}O_5$ requires C, 72·5; H, 8·9%).

Oxidation of the Diolone (V; R = Ac, R′ = H).—Bromine (600 mg.) in chloroform (20 ml.) was added dropwise during 45 min. to a stirred solution of the dihydroxy-ketone (1·5 g.) in chloroform (20 ml.) at −60°. After removal of the solvent *in vacuo* at +30°, the residue in acetic acid (30 ml.) was treated with chromium trioxide (1 g.) in 80% acetic acid (10 ml.), and the mixture kept overnight. Zinc dust (6 g.) was then added, and the mixture stirred for 10 min., then heated for 10 min. at 100°. The product obtained on dilution with water was extracted with ether. The acidic fraction (0·66 g.; m. p. *ca.* 230°) was purified from aqueous ethanol to give 3β-acetoxy-16 : 17-*seco*androst-5-ene-16 : 17-dioic acid, plates, m. p. and mixed m. p. 258—260°, $[\alpha]_D^{20}$ −97° (*c*, 1·33) (Found : C, 66·7; H, 8·1. Calc. for $C_{21}H_{36}O_6$: C, 66·6; H, 8·0%).

3β : 17-*Dihydroxy*-17*a*-*methyl*-D-*homoandrosta*-5 : 17-*dien*-16-*one* (VI; R = H).—A solution of the diolone (V; R = Ac; R′ = H) (2·3 g.) in methanolic potassium hydroxide (50 ml. of 10%) was refluxed for 2 hr., a yellow insoluble potassium salt separating after the first hour. The product obtained on dilution and acidification to Congo-red was crystallised from aqueous methanol. The diosphenol (1·1 g.) formed fine hair-like needles, m. p. 196°, $[\alpha]_D^{22}$ −67° (*c*, 0·84) (Found : C, 76·3; H, 9·2. Calc. for $C_{21}H_{30}O_3$: C, 76·3; H, 9·2%). Light absorption : $\lambda_{max.}$ 277 mμ (ε 8000) [Inhoffen *et al.*, *loc. cit.*, give m. p. 186—187°, $\lambda_{max.}$ 277 mμ (ε 9120)]. The 3β : 17-diacetate, prepared by acetylation in pyridine for 30 min. at 100°, crystallised from aqueous methanol in prisms, m. p. 209—210°, $[\alpha]_D^{20}$ −66° (*c*, 1·26) (Found : C, 72·5; H, 8·2.

Calc. for $C_{25}H_{34}O_5$: C, 72·45; H, 8·25%). Light absorption : $\lambda_{max.}$ 245 mμ (ε 11,830) [Inhoffen *et al., loc. cit.*, give m. p. 197—198°, $[\alpha]_D^{19}$ −68·4°, $\lambda_{max.}$ 244 mμ (ε 11,230)]. The *quinoxaline* derivative, prepared by heating the diosphenol (200 mg.) and *o*-phenylenediamine (200 mg.) in absolute ethanol (4 ml.) under reflux for 3 hr., formed almost colourless needles (from aqueous methanol), m. p. 254° (Found : C, 80·7; H, 8·7; N, 6·7. $C_{27}H_{34}ON_2$ requires C, 80·55; H, 8·5; N, 6·95%).

The diosphenol (VI; R = H) was also obtained by similar treatment of the diolone (III; R = H) with methanolic potassium hydroxide.

3β-*Hydroxy*-17*a*-*methyl*-16 : 17-seco-D-*homoandrost*-5-*ene*-16 : 17-*dioic acid* (IX).—The foregoing diosphenol (1 g.) in ethanol (100 ml.) was treated with hydrogen peroxide (2·5 ml.; " 130 vol."), followed by 10% aqueous potassium hydroxide (8 ml.). After 18 hr. at room temperature the mixture was diluted with water and extracted twice with ether, and the aqueous phase acidified with hydrochloric acid. The solids (350 mg.; m. p. 135—140°) which slowly separated were crystallised from aqueous acetic acid. The *dicarboxylic acid* formed needles which melted with effervescence at 145°, resolidified, and finally melted at 258—259°, $[\alpha]_D^{20}$ −65° (*c*, 0·74 in EtOH) (Found : C, 63·0; H, 9·0; equiv., 210. $C_{21}H_{32}O_5.2H_2O$ requires C, 63·0; H, 9·05%; equiv., 200).

3β : 16α-*Diacetoxy*-17α-*hydroxy*allo*pregnan*-20-*one*.—Osmium tetroxide (5 g.) in ether (150 ml.) was added to 3β-acetoxy*allo*pregn-16-en-20-one (7 g.) in ether (300 ml.) and pyridine (4·5 ml.). After several hours, the complex (13·8 g.) was obtained as light brown needles.

The complex (1 g.), suspended in a solution of mannitol (2 g.) and potassium hydroxide (0·5 g.) in water (50 ml.), was heated at 100° for 5 min. The insoluble solids were dried and acetylated in pyridine to give a gum which crystallised from methanol. 3β : 16α-Diacetoxy-17α-hydroxy*allo*pregnan-20-one (90 mg.) formed needles, m. p. 158—160°, alone or in admixture with an authentic specimen (Part I).

3β : 16β : 17*a*β-*Trihydroxy*-17*a*α-*methyl*-D-*homoandrostan*-17-*one*.—A solution of the foregoing complex (8 g.) in ethanol (140 ml.) was added to sodium sulphite (20 g.) in water (100 ml.). The mixture was refluxed for 45 min., then filtered, and the product isolated by extraction with methylene dichloride. Concentration of the dried extract to *ca.* 50 ml. gave a crystalline solid (1·22 g.; m. p. 258—262°) which was purified from aqueous methanol. The D-*homo-steroid* formed needles, m. p. 260—262°, $[\alpha]_D^{22}$ +23° (*c*, 0·73) (Found : C, 71·5; H, 9·9. $C_{21}H_{34}O_4$ requires C, 72·0; H, 9·8%). Further concentration of the methylene dichloride mother-liquor gave a gum from which crystalline material could not be isolated. Acetylation of the trihydroxy-ketone in pyridine for 1 hr. at 100° gave the 3β : 16β : 17*a*β-*triacetoxy-derivative*, leaflets (from aqueous methanol), m. p. 172—174°, $[\alpha]_D^{21}$ +35° (*c*, 0·91) (Found : C, 68·0; H, 8·4. $C_{27}H_{40}O_7$ requires C, 67·9; H, 8·45%).

16α : 17α-*Dihydroxypregn*-4-*ene*-3 : 20-*dione* (XII).—Osmium tetroxide (5 g.) in ether (150 ml.) was added to pregna-4 : 16-diene-3 : 20-dione (6 g.) in ether (800 ml.) and pyridine (4 ml.). After 1 hr. the complex (13 g.) was obtained as dense brown needles.

The complex (2 g.), suspended in a solution of mannitol (4 g.) and potassium hydroxide (1 g.) in water (50 ml.), was heated for 10 min. at 80°. The almost colourless solid (300 mg.) obtained on filtration was crystallised from ethanol to give 16α : 17α-dihydroxypregn-4-ene-3 : 20-dione, dense prisms, m. p. 225°, alone or in admixture with an authentic specimen (Part I, *loc. cit.*).

16β : 17*a*β-*Dihydroxy*-17*a*α-*methyl*-D-*homoandrost*-4-*ene*-3 : 17-*dione* (XIII; R = H).—(*a*) A mixture of the foregoing complex (8 g.), sodium sulphite (20 g.), ethanol (140 ml.), and water (100 ml.) was refluxed for 30 min. and then filtered. The product, isolated with methylene dichloride in the usul way, was crystallised from acetone–*n*-hexane to give material (1·5 g.; m. p. 190—195°). Recrystallised from ethanol–*n*-hexane, the D-homo-steroid formed needles, m. p. 223—225°, $[\alpha]_D^{20}$ +80° (*c*, 0·8) (Found : C, 72·3; H, 8·7. Calc. for $C_{21}H_{30}O_4$: C, 72·8; H, 8·7%). Light absorption : $\lambda_{max.}$ 239 mμ (ε 16,600). No depression in m. p. was obtained in admixture with a specimen prepared by the method of Inhoffen *et al., loc. cit.*

(*b*) A mixture of 16α : 17α-dihydroxypregn-4-ene-3 : 20-dione (500 mg.), sodium sulphite (1 g.), ethanol (20 ml.), and water (10 ml.) was refluxed for 1 hr., then diluted with water, and the product isolated with methylene dichloride. Crystallisation from acetone–*n*-hexane gave 16β : 17*a*β-dihydroxy-17*a*α-methyl-D-homoandrost-4-ene-3 : 17-dione (350 mg.), identified by m. p. and mixed m. p. with a specimen prepared by method (*a*).

Acetylation of this dione in pyridine for 24 hr. at room temperature gave the 16β : 17*a*β-*diacetate*, plates (from aqueous ethanol), m. p. 201—202°, $[\alpha]_D^{22}$ +91° (*c*, 0·88) (Found : C, 69·9, 69·5; H, 8·1, 8·15. $C_{25}H_{34}O_6$ requires C, 69·75; H, 8·0%).

16α : 17aα-Dihydroxy-17aβ-methyl-D-homoandrost-4-ene-3 : 17-dione (X; R = H).—**16α : 17α**-Dihydroxypregn-4-ene-3 : 20-dione (3 g.) in benzene–methylene dichloride (320 ml.; 3 : 1) was passed slowly through a column (18 × 2 cm.) of alkaline alumina. The product was crystallised from ethanol–*n*-hexane to give the D-*homo-steroid* (1·8 g.), needles, m. p. 190°, $[\alpha]_D^{21}$ +96° (*c*, 0·86) (Found: C, 72·4; H, 8·7. $C_{21}H_{30}O_4$ requires C, 72·8; H, 8·7%). Acetylation in pyridine gave the **16α-acetoxy-derivative**, needles (from acetone–*n*-hexane), m. p. 202—203°, $[\alpha]_D^{20}$ +32° (*c*, 0·76) (Found: C, 71·0; H, 8·3. $C_{23}H_{32}O_5$ requires C, 71·1; H, 8·3%). The iso*propylidene derivative* (90%), prepared by keeping the diol (400 mg.) in hot acetone (20 ml.) with 2 drops of concentrated hydrochloric acid overnight, formed small rhombs (from aqueous ethanol), m. p. 231—232°, $[\alpha]_D^{22}$ +68° (*c*, 0·67) (Found: C, 74·6; H, 9·0. $C_{24}H_{34}O_4$ requires C, 74·6; H, 8·9%).

Cleavage of Inhoffen, Blomeyer, and Brückner's Complex Under Modified Conditions.—The complex was prepared by treating pregna-4 : 16-diene-3 : 20-dione (2·5 g.) in ether (350 ml.) with osmium tetroxide (2 g.) in ether (100 ml.). After 4 days, the dark brown precipitate (3·65 g.) was collected and washed with ether.

The complex (3 g.), sodium sulphite (13 g.), zinc bromide (1·5 g.), zinc dust (5 g.), ethanol (100 ml.), and water (150 ml.) were stirred and refluxed for 3 hr. After filtration, the filtrate was diluted, and the product isolated by extraction with methylene chloride. Crystallisation from acetone–*n*-hexane gave **16β : 17aβ-dihydroxy-17aα-methyl-D-homoandrost-4-ene-3 : 17-dione** (350 mg.), m. p. and mixed m. p. 223—225°. The acetone–*n*-hexane mother-liquor deposited stout prisms (150 mg.) of **16α : 17aα-dihydroxy-17aβ-methyl-D-homoandrost-4-ene-3 : 17-dione**, m. p. and mixed m. p. 190°.

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Hydroxylation of Pregn-16-en-20-ones. Part III. Formation of 3β-Acetoxy-16α : 17α-dihydroxypregna-5 : 14-dien-20-one and 16α-Hydroxy-derivatives of "Compound S" and of Cortisone.*

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Oxidation of 3β-acetoxypregna-5 : 16-dien-20-one (I) with potassium permanganate in acetone containing acetic acid can give rise not only to 3β-acetoxy-16α : 17α-dihydroxypregn-5-en-20-one (II) (see Parts I and II*), but also to its 14 : 15-dehydro-derivative (III). The latter product closely resembles the former in its behaviour on D-homo-annulation with basic alumina; the diolone (IV; R = H) is obtained, and undergoes alkaline dehydration to (VII). Oxidation of the dibromide of the dehydro-compound yields the Köster–Logemann ketone (VI).

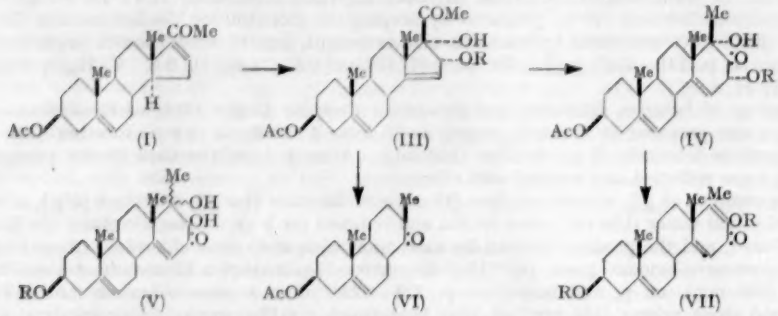
The method of hydroxylation developed in Part I has been extended to the preparation of 16α-hydroxy-"Compound S" (acetate) (XII; R = H_2, R′ = H) and of 16α-hydroxycortisone (acetate) (XII; R = O, R′ = H) from 21-acetoxypregna-4 : 16-diene-3 : 20-dione (XI; R = H_2) and 21-acetoxypregna-4 : 16-diene-3 : 11 : 20-trione (XI; R = O), respectively.

(i) IN Part I* oxidation of 3β-acetoxypregna-5 : 16-dien-20-one (I) with potassium permanganate in acetone containing a limited quantity of acetic acid was shown to give a crystalline mixture from which 3β-acetoxy-16α : 17α-dihydroxypregn-5-en-20-one (II) was readily obtained; several crystallisations were required to free it from a contaminant (compound X). The amount of acetic acid critically affected the relative proportions of these products; in its absence the oxidation gave only the ketone (II), but in very low yield. When 1·2 mols. of acetic acid, relative to potassium permanganate, were used, the yield of this ketone rose to 20%, but compound X could be identified, though with difficulty. Larger

* Parts I and II, preceding papers.

amounts of acetic acid decreased the yield of the ketone (II) and increased that of compound X, which was the sole product (30%) when 15 mols. of acid were used.

Compound X had not the ultraviolet absorption spectrum of an αβ-unsaturated ketone (cf. I). Its analysis approached that required by (II), from which, however, it differed in optical rotation. The presence, in its molecule, of *cis*-hydroxy-groups (one secondary and one tertiary) followed from the ready formation of an *iso*propylidene derivative and a



diacetate. Treatment with one equivalent of bromine, followed by chromic acid and debromination, furnished the Köster–Logemann ketone, 7β-acetoxy-$\Delta^{9:14}$-dodecahydro-2 : 13-dimethyl-1-oxophenanthrene (VI) (Köster and Logemann, *Ber.*, 1940, **73**, 298), which established the presence of a 5 : 6-ethylenic linkage and of a 14 : 15-unsaturated linkage (not evident from the analytical data). That two double bonds are present was confirmed by perbenzoic acid titration.

The ready formation of this new oxidation product from the ketone (I) under mildly acidic conditions which are not favourable to the D-homo-annulation of 17-hydroxypregnan-20-ones, together with results recorded above and in Parts I and II, led us to assign the constitution of 3β-acetoxy-16α : 17α-dihydroxypregna-5 : 14-dien-20-one (III; R = H) to compound X. Its formation is regarded as taking place by allylic oxidation at $C_{(15)}$, dehydration to a 5 : 14 : 16-trien-20-one, and hydroxylation (cf. the formation of ergosta-7 : 14 : 22-triene-3β : 5α : 6α-triol from ergosterol by oxidation with potassium permanganate; Fieser, Quilico, Nickon, Rosen, Tarlton, and Fieser, *J. Amer. Chem. Soc.*, 1953, **75**, 4066).

D-Homo-annulation of the diene (III; R = H) was closely similar to that of the monoene (II) (cf. preceding communication): chromatography on basic alumina led to an isomer, 3β-acetoxy-16α : 17*a*α-dihydroxy-17*a*β-methyl-D-homoandrosta-5 : 14-dien-17-one (IV; R = H), which formed a diacetate (IV; R = Ac) on acetylation in pyridine and an *iso*propylidene derivative on treatment with acetone and hydrochloric acid. The alternative formulation of the D-homo-steroid as (V; R = Ac) is excluded in this instance by the transparency of the compound to ultraviolet light in the region 220—300 mμ, which establishes the absence of an αβ-unsaturated ketonic system. As ethylene linkages tend towards conjugation, the formation of the diene (IV; R = H) and not the isomer (V; R = Ac) from the dehydro-compound (III; R = H) provides further evidence in support of the formulation previously assigned in Part II to the alumina-catalysed D-homo-annulation product of the monoene (II).

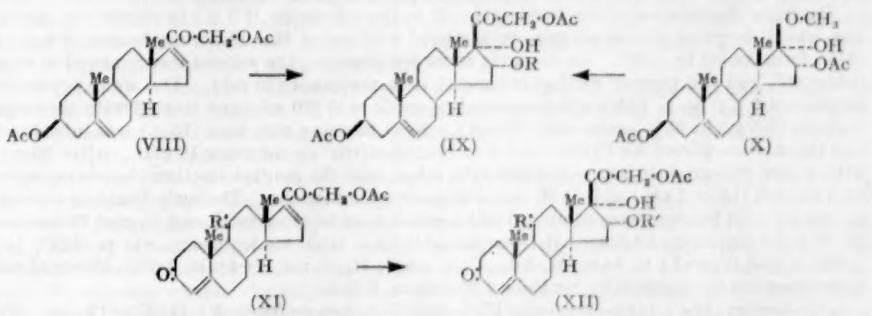
Hot methanolic potassium hydroxide converted the D-homo-compound (IV; R = H), presumably by dehydration of an initially formed (not isolated) product (V; R = H) of α-ketol rearrangement, into a diosphenol, $C_{21}H_{28}O_3$, which gave a purple colour with ethanolic ferric chloride, a quinoxaline derivative, and a diacetate. This ester is regarded as 3β : 17-diacetoxy-17*a*-methyl-D-homoandrosta-5 : 14 : 17-trien-16-one (VII; R = Ac), and its ultraviolet absorption (max. at 246·5 mμ; ε 17,600) is consistent with this. The spectrum of the parent diosphenol, however, shows 2 bands [max. at 252 (ε 11,740) and 300 mμ (ε 3960)], the first of which is not inconsistent with the condition of cross-conjugation shown in (VII; R = H); the second band is much too intense to be due to a carbonyl

group and may indicate that in solution the enol (VII; R = H) is in equilibrium with a second form (see Dorfman, *Chem. Rev.*, 1953, **53**, 79—83).

Alkaline hydrolysis of the *iso*propylidine derivative of the diol (III; R = H) gave the corresponding 3-alcohol, which passed into 16α : 17α-*iso*propylidenedioxypregna-4 : 14-diene-3 : 20-dione on Oppenauer oxidation. The last compound was recovered unchanged after prolonged treatment with hot aqueous acetic acid.

(ii) Oxidation of 3β : 21-diacetoxypregna-5 : 16-dien-20-one (VIII) (Djerassi and Lenk, *J. Amer. Chem. Soc.*, 1954, **76**, 1722) with potassium permanganate in acetone containing a limited quantity of acetic acid led to a dihydroxy-derivative of (VIII) which (*a*) did not show the ultraviolet absorption spectrum of an αβ-unsaturated ketone, (*b*) readily formed an *iso*propylidene derivative (*cis*-glycol group), and (*c*) passed into a triacetate on acetylation in pyridine, thus establishing that only one of the two new hydroxyl groups is secondary. We therefore assign it the constitution of 3β : 21-diacetoxy-16α : 17α-dihydroxypregn-5-en-20-one (IX; R = H) and in support find that its triacetate (IX; R = Ac) may be prepared by an alternative route involving the reaction sequence: (*a*) tribromination of 3β : 16α-diacetoxy-17α-hydroxypregn-5-en-20-one (X) (Part I), (*b*) conversion of the 5 : 6 : 21-tribromide into the corresponding Δ^5-21-iodo-compound by reaction with sodium iodide, and (*c*) treatment with potassium acetate in boiling acetone to give the triacetate (IX; R = Ac). Its formulation as the 14 : 15-dehydro-derivative of (IX; R = H) [cf. preceding section] is thereby excluded. The triacetate (IX; R = Ac), it may be added, differs from 3β : 16β : 21-triacetoxy-17α-hydroxypregn-5-en-20-one (Heusler and Wettstein, *Chem. Ber.*, 1954, **87**, 1301), with which it is epimeric at $C_{(16)}$.

Oxidation of 21-acetoxypregna-4 : 16-diene-3 : 20-dione (XI; R = H_2) (Cole and Julian, *J. Org. Chem.*, 1954, **19**, 131) with potassium permanganate under similar experimental conditions led to a dihydroxy-derivative, regarded as 21-acetoxy-16α : 17α-dihydroxypregn-4-ene-3 : 20-dione (XII; R = H_2, R′ = H) on the basis of (*a*) its method of preparation, (*b*) its ultraviolet absorption spectrum (max. at 240 mμ; ε 16,900), (*c*) its conversion into



an *iso*propylidene derivative, and (*d*) its acetylation to a diacetate. The constitution of 16α : 21-diacetoxy-17α-hydroxypregn-4-ene-3 : 20-dione assigned to the last compound is supported by its molecular rotation (see Table), which falls unequivocally within the expected range.

Molecular-rotation differences of epimeric 16-*acetoxypregnan*-20-*ones.*

	16α-Acetoxy	16β-Acetoxy	$[M]_D^{\beta} - [M]_D^{\alpha}$
3β : 16-Diacetoxy-17α-hydroxypregn-5-en-20-one	−320° [a]	−104° [d]	+216°
16-Acetoxy-17α-hydroxypregn-4-ene-3 : 20-dione	+190 [a]	+392 [e]	+202
3β : 16 : 21-Triacetoxy-17α-hydroxypregn-5-en-20-one...	−333 [b]	−118 [e]	+215
16 : 21-Diacetoxy-17α-hydroxypregn-4-ene-3 : 20-dione	+232 [b]	+442 [e]	+210

[a] Part I (*loc. cit.*). [b] Present paper. [c] Heusler and Wettstein (*loc. cit.*). [d] Heusler and Wettstein give $[M]_D$ − 164°. The value shown was obtained in the present work.

21-Acetoxypregn-4 : 16-diene-3 : 11 : 20-trione (XI; R = O) (Allen and Bernstein, *J. Amer. Chem. Soc.*, 1955, **77**, 1028; McGuckin and Mason, *ibid.*, p. 1822) with potassium

permanganate gave 21-acetoxy-16α : 17α-dihydroxypregn-4-ene-3 : 11 : 20-trione (XII; R = O, R′ = H), which formed a diacetate (XII; R = O, R′ = Ac). The infrared absorption (kindly determined by Dr. A. E. Kellie, Courtauld Institute of Biochemistry) of the latter compound is entirely consistent with the proposed structure.

Experimental

3β-Acetoxy-16α : 17α-dihydroxypregna-5 : 14-dien-20-one (III; R = H).—A solution of potassium permanganate (18 g.) in aqueous acetone (1·05 l. of 85%) was added during 30 min. to a stirred ice-cooled solution of 3β-acetoxypregna-5 : 16-dien-20-one (40 g.) in a mixture of acetone (1·2 l.) and acetic acid (100 ml.). After treatment with sulphur dioxide, the solution was decanted from inorganic salts, and most of the solvents were removed by distillation *in vacuo*. The product was extracted into ether (*ca.* 2 l.), and the extract washed with water, aqueous sodium hydrogen carbonate, and water, and then dried. Concentration to crystallisation, followed by cooling to 0°, gave a product (21 g.; m. p. 185—203°) from which, after two crystallisations from methanol, *3β-acetoxy-16α : 17α-dihydroxypregna-5 : 14-dien-20-one* (12 g.) was obtained as needles, m. p. 220—222°, $[\alpha]_D^{20}$ −107° (*c*, 1·25) (Found: C, 70·8; H, 8·4. $C_{23}H_{32}O_5$ requires C, 71·1; H, 8·3%). On treatment with perbenzoic acid in benzene–chloroform for 3 days at 0°, 373 mg. were oxidised by 254 mg. of perbenzoic acid, equiv. to 1·99 atoms of oxygen. In admixture with 3β-acetoxy-16α : 17α-dihydroxypregn-5-en-20-one, m. p. 210—212° (Part I, *loc. cit.*), an m. p. of 213—215° was obtained.

Acetylation in pyridine for 1 hr. at 100° gave the *3β : 16α-diacetate* (III; R = Ac), flat needles (from aqueous ethanol), m. p. 178°, $[\alpha]_D^{21}$ −136° (*c*, 0·91) (Found: C, 69·2; H, 8·1. $C_{25}H_{34}O_6$ requires C, 69·7; H, 8·0%) after drying for several hours at 120°.

3β-Acetoxy-16α : 17α-isopropylidenedioxypregna-5 : 14-dien-20-one.—The diene (III; R = H) (4 g.) in boiling acetone (150 ml.) was treated with 3 drops of concentrated hydrochloric acid and the mixture kept overnight. The solids obtained on dilution with water were purified from methanol. The *isopropylidene derivative* (3·6 g.) formed fine needles, m. p. 184°, $[\alpha]_D^{22}$ −40° (*c*, 1·29) (Found: C, 73·0; H, 8·6. $C_{26}H_{36}O_5$ requires C, 72·9; H, 8·5%).

Oxidative Degradation of the Diene (III; R = H).—Bromine (1·7 g.) in chloroform (30 ml.) was added dropwise during 45 min. to a stirred solution of the dihydroxy-ketone (3·9 g.) in chloroform cooled to −60°. On reaching room temperature, the solvent was removed *in vacuo* below 40°, and the gummy residue triturated with methanol (20 ml.). The white crystalline product (4·6 g.; m. p. 155°) was suspended in acetic acid (70 ml.) and treated with chromium trioxide (3·5 g.) in 85% acetic acid (25 ml.). Next morning zinc dust (15 g.) was introduced, and the mixture stirred for 10 min. and then heated at 100° for a further 10 min. After dilution with water, the product was extracted with ether, and the neutral fraction chromatographed on a column (12 × 2 cm.) of B.D.H. alumina made up in benzene. The early fractions obtained on elution with benzene were combined and purified from aqueous methanol, to give 7β-acetoxy-$\Delta^{9:14}$-dodecahydro-2 : 13-dimethyl-1-oxophenanthrene (400 mg.), blades, m. p. 129°, $[\alpha]_D^{20}$ −90° (*c*, 0·5) (Found: C, 74·6; H, 9·0. Calc. for $C_{18}H_{26}O_3$: C, 74·4; H, 9·0%), identical with a specimen kindly supplied by Sir Robert Robinson, F.R.S.

3β-Acetoxy-16α : 17aα-dihydroxy-17aβ-methyl-D-homoandrosta-5 : 14-dien-17-one (IV; R = H).—A solution of the dihydroxy-ketone (III; R = H) (2 g.) in methylene dichloride–ethanol (40 ml.; 9 : 1) was passed slowly through a column (10 × 2 cm.) of alkaline alumina. Elution with the same solvent mixture gave a product (1·9 g.; m. p. 167—169°), readily purified from aqueous acetone. The *D-homo-steroid* separated in hexagonal plates, m. p. 175—176°, $[\alpha]_D^{23}$ −7° (*c*, 0·96) (Found: C, 71·0; H, 8·5. $C_{23}H_{32}O_5$ requires C, 71·1; H, 8·3%). Acetylation in pyridine gave the *3β : 16α-diacetoxy-derivative*, needles (from aqueous methanol), m. p. 169°, $[\alpha]_D^{20}$ −157° (*c*, 0·99) (Found: C, 69·5; H, 8·1. $C_{25}H_{34}O_6$ requires C, 69·7; H, 8·0%). The *isopropylidene derivative* formed plates (from aqueous acetone), m. p. 166—168°, $[\alpha]_D^{20}$ +20° (*c*, 1·0) (Found: C, 72·7; H, 8·2. $C_{26}H_{36}O_5$ requires C, 72·9; H, 8·5%).

Action of Hot Methanolic Potassium Hydroxide on the D-Homo-compound (IV; R = H).—The D-homo-steroid (1 g.) in methanolic 12% potassium hydroxide (25 ml.) was refluxed for 4 hr., a yellow crystalline potassium salt separating after the first 1½ hr. A suspension of the salt in ether (100 ml.)–water (75 ml.) was treated with concentrated hydrochloric acid (1 ml.), the mixture vigorously shaken, and the ethereal layer washed, dried, and evaporated. The residue was purified from aqueous ethanol to give the *diosphenol* (60%), needles, m. p. 185—186°, $[\alpha]_D^{23}$ +161° (*c*, 1·1) (Found: C, 76·6; H, 8·75. $C_{21}H_{28}O_3$ requires C, 76·8; H, 8·6%). Light

absorption: max. at 252 (ε 11,740) and 300 mμ (ε 3960). Acetylation in pyridine for 15 min. at 100° gave 3β : 17-*diacetoxy*-17α-*methyl*-D-*homoandrosta*-5 : 14 : 17-*trien*-16-*one* (VII; R = Ac), needles (from aqueous ethanol), m. p. 225—226°, $[\alpha]_D^{19}$ +71° (*c*, 0·8) (Found: C, 73·0; H, 8·0. $C_{25}H_{32}O_5$ requires C, 72·8; H, 7·8%). Light absorption: max. at 246·5 mμ (ε 17,600). The *quinoxaline derivative*, prepared by heating the diosphenol (250 mg.) with *o*-phenylenediamine (150 mg.) for 30 min. at 150°, crystallised from ethanol in pale yellow needles, m. p. 258—260° (Found: C, 80·6; H, 8·1; N, 7·05. $C_{37}H_{38}ON_2$ requires C, 81·0; H, 8·05; N, 7·0%).

16α : 17α-iso*Propylidenedioxypregna*-4 : 14-*diene*-3 : 20-*dione*.—3β-Acetoxy-16α : 17α-*iso*propylidenedioxypregna-5 : 14-dien-20-one (3·1 g.) in methanolic 1% potassium hydroxide (100 ml.) was refluxed for 45 min. Addition of water gave needles (2·55 g.), m. p. 225° (Found: C, 74·4; H, 9·1. $C_{24}H_{34}O_4$ requires C, 74·6; H, 8·9%). A solution of this *product* (2·5 g.) in toluene (80 ml.) and *cyclo*hexanone (20 ml.) was distilled until 25 ml. of distillate had collected. Aluminium *iso*propoxide in toluene (18 ml. of 25% solution) was added, and the mixture refluxed for 30 min., cooled, and extracted with concentrated aqueous Rochelle salt. Removal of solvents by steam-distillation, followed by purification of the residue from aqueous ethanol, gave 16α : 17α-iso*propylidenedioxypregna*-4 : 14-*diene*-3 : 20-*dione*, needles, m. p. 200—202°, $[\alpha]_D^{21}$ +73·5 (*c*, 0·95) (Found: C, 74·6; H, 8·3. $C_{24}H_{32}O_4$ requires C, 75·0; H, 8·4%). In admixture with 16α : 17α-*iso*propylidenedioxypregn-4-en-3 : 20-dione, m. p. 210° (Part I), m. p. 204—205° was obtained.

The compound was recovered substantially unchanged after being heated in aqueous acetic acid (70%) for 2 hr. at 100°.

3β : 21-*Diacetoxy*-16α : 17α-*dihydroxypregn*-5-*en*-20-*one* (IX; R = H).—A solution of potassium permanganate (3·2 g.) in aqueous acetone (175 ml. of 85%) was added dropwise during 30 min. to a stirred ice-cooled solution of 3β : 21-diacetoxypregna-5 : 16-dien-20-one (7 g.) in acetone (200 ml.) and acetic acid (3 ml.). After treatment with sulphur dioxide, the solution was decanted from inorganic salts, and most of the solvents removed *in vacuo*. The product was extracted into ether, and the extract washed with water, aqueous sodium hydrogen carbonate, water, and then dried. The crude material (3·95 g.; m. p. 180—215°) obtained on partial removal of the solvent was purified from methylene dichloride–methanol, to give 3β : 21-*diacetoxy*-16α : 17α-*dihydroxypregn*-5-*en*-20-*one*, flat needles, m. p. 235—237°, $[\alpha]_D^{21}$ −53° (*c*, 1·0) (Found: C, 66·8; H, 7·7. $C_{25}H_{36}O_7$ requires C, 66·9; H, 8·1%). The iso*propylidene derivative* formed needles (from aqueous acetone), m. p. 194—195°, $[\alpha]_D^{20}$ −16° (*c*, 0·68) (Found: C, 69·0; H, 8·1. $C_{28}H_{40}O_7$ requires C, 68·8; H, 8·25%).

3β : 16α : 21-*Triacetoxy*-17α-*hydroxypregn*-5-*en*-20-*one* (IX; R = Ac).—(*a*) Acetylation of the foregoing dihydroxy-ketone (IX; R = H) in pyridine for 18 hr. at room temperature gave the *triacetate*, needles (from methanol), m. p. 214—215°, $[\alpha]_D^{22}$ −68° (*c*, 0·97) (Found: C, 66·1; H, 7·7. $C_{27}H_{38}O_8$ requires C, 66·1; H, 7·8%).

(*b*) Bromine (2·25 g.) in carbon tetrachloride (10 ml.) was added dropwise during 30 min. to 3β : 16α-diacetoxy-17α-hydroxypregn-5-en-20-one (3 g.) in 1 : 1 carbon tetrachloride–acetic acid (60 ml.). The product obtained by dilution with water and isolation with carbon tetrachloride was dissolved in benzene (60 ml.) and treated for 24 hr. with sodium iodide (12 g.) in ethanol (70 ml.). The mixture was poured into water and extracted with ether, and the extract washed with 3% aqueous sodium thiosulphate and water, and dried. The brown gum obtained on removal of the solvent was triturated with ethanol–*n*-hexane to give a cream-coloured solid [0·8 g.; m. p. 190° (decomp.)]. This material, in acetone (40 ml.) containing freshly fused potassium acetate (4 g.), was heated under reflux for 18 hr., and the solids obtained on the addition of water were purified from methanol. 3β : 16α : 21-Triacetoxy-17α-hydroxypregn-5-en-20-one separated in needles, m. p. 214—215°, not depressed in admixture with a specimen prepared by method (*a*).

21-*Acetoxy*-16α : 17α-*dihydroxypregn*-4-*ene*-3 : 20-*dione* (XII; R = H_2, R′ = H).—Potassium permanganate (800 mg.) in aqueous acetone (40 ml. of 85%) was added dropwise during 40 min. to a stirred ice-cooled solution of 21-acetoxypregna-4 : 16-diene-3 : 20-dione (1·75 g.) in acetone (50 ml.) containing acetic acid (0·5 ml.). After treatment with sulphur dioxide, the mixture was diluted with water, and the product isolated with ether. Crystallisation from acetone–*n*-hexane gave material (420 mg.; 194—198°), followed by a second crop (370 mg.; m. p. 180—185°). The combined crops, purified from ethyl acetate–*n*-hexane, gave 21-*acetoxy*-16α : 17α-*dihydroxypregn*-4-*ene*-3 : 20-*dione*, needles, m. p. 200—202°, $[\alpha]_D^{20}$ +121° (*c*, 0·63) (Found: C, 68·0; H, 8·0. $C_{23}H_{32}O_6$ requires C, 68·3; H, 8·0%). Light absorption: max. at 240 mμ (ε 16,900). The iso*propylidene derivative* separated from aqueous ethanol in needles, m. p. 249—250°, $[\alpha]_D^{22}$ +133° (*c*, 0·53) (Found: C, 69·8; H, 8·1. $C_{26}H_{36}O_6$ requires C, 70·2;

H, 8·2%). Acetylation in pyridine gave **16α : 21-*diacetoxy*-17α-*hydroxypregn*-4-*ene*-3 : 20-*dione***, flat needles (from aqueous methanol), m. p. 199—200°, $[\alpha]_D^{20}$ +52° (*c*, 0·78) (Found: C, 66·2; H, 7·7. $C_{25}H_{34}O_7$ requires C, 67·2; H, 7·7%) after drying for 5 hr. at 100°. The dried material was hygroscopic. The compound separated from aqueous solvents in a hydrated form, m. p. 115—120° (effervescence).

21-*Acetoxy*-16α : 17α-*dihydroxypregn*-4-*ene*-3 : 1 : 20-*trione* (XII; R = O, R′ = H).—21-Acetoxypregna-4 : 16-diene-3 : 11 : 20-trione (1·7 g.) was oxidised with potassium permanganate (800 mg.) as in the preceding preparation. The crude product was triturated with warm methanol (10 ml.), and the insoluble fraction (510 mg.; m. p. 245°) purified from aqueous dioxan. **21-*Acetoxy*-16α : 17α-*dihydroxypregn*-4-*ene*-3 : 11 : 20-*trione*** separated in needles, m. p. 245—247°, $[\alpha]_D^{22}$ +166·5° (*c*, 0·97 in dioxan) (Found: C, 66·2; H, 7·1. $C_{23}H_{30}O_7$ requires C, 66·0; H, 7·2%). Light absorption: max. at 238 mμ (ε 15,900). Acetylation in pyridine gave the **16α : 21-*diacetate***, needles (from 95% ethanol), double m. p. 185° and 225—226° (after drying for 2 hr. at 100°), $[\alpha]_D^{20}$ +118° (*c*, 0·43) (Found: C, 64·0; H, 7·1. $C_{25}H_{32}O_8.\frac{1}{2}H_2O$ requires C, 63·95; H, 7·1%).

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N-*Thiocarbamoylglycine and its Ethyl Ester.*

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The compound described in the literature as ethyl thiohydantoate (*N*-thiocarbamoylglycine ethyl ester) (I; R = OEt) is glycine ethyl ester thiocyanate (II; R = OEt). The authentic ester (I) has been prepared by two methods and its structure has been proved. Acid catalysis induced cyclisation of *N*-thiocarbamoylglycine (I; R = OH) and its ethyl ester (I; R = OEt) to 2-thiohydantoin. The latter also resulted from the action of ammonia on the ester (I; R = OEt); the mechanism of the reaction between ethyl *iso*thiocyanatoacetate and ammonia is discussed briefly in relation to this observation.

HARRIES AND WEISS (*Ber.*, 1900, **33**, 3418; *Annalen*, 1903, **327**, 355) and Johnson (*J. Amer. Chem. Soc.*, 1913, **35**, 780) found that interaction of glycine ethyl ester hydrochloride and potassium thiocyanate in boiling ethanol afforded a compound, m. p. 65°, which they concluded was *N*-thiocarbamoylglycine ethyl ester (I; R = OEt). The surprising fact that the latter did not produce 2-thiohydantoin with hydrochloric acid was reported by both groups of workers, although Klason (*Ofv. Kongl. Vet. Akad.*, 1890, 87) and Johnson (*loc. cit.*) agreed that a mixture of potassium thiocyanate and glycine ethyl ester hydrochloride at 140—150° without solvent formed 2-thiohydantoin directly.

(I) $NH_2{\cdot}CS{\cdot}NH{\cdot}CH_2{\cdot}CO{\cdot}R$ $\qquad$ $R{\cdot}CO{\cdot}CH_2{\cdot}NH_3^+\ SCN^-$ (II)

We obtained the compound, m. p. 65°, as described by Harries and Weiss and by Johnson (*locc. cit.*) and attempted to promote cyclisation in nitromethane saturated with dry hydrogen chloride (Edman, *Acta Chem. Scand.*, 1950, **4**, 283). Glycine ethyl ester hydrochloride was the sole product. At first, we suspected that the difference in behaviour towards acids between the compound, m. p. 65°, and other *N*-thiocarbamoyl derivatives of animo-acids and peptides (Ware, *Chem. Rev.*, 1950, **46**, 403; Edman, *loc. cit.*; Elmore and Toseland, *J.*, 1954, 4533) might be due to a difference in fine structure between *N*-monosubstituted and *NN′*-disubstituted thioureas. Thus, Clow (*Trans. Faraday Soc.*, 1938, **34**, 457) has adduced evidence that the former have a greater tendency than the latter to exist predominantly in the *iso*thiourea form. Other experiments which we performed seemed at first consonant with this interpretation. On the one hand, treatment of the compound, m. p. 65°, with alkyl halides and, on the other, the reaction between *N*-cyanoglycylglycine ethyl ester and ethanethiol in presence of dry hydrogen chloride, which might be expected

to produce *iso*thiourea derivatives, afforded only hydrohalides of glycine ethyl ester and glycylglycine ethyl ester respectively. There was no reaction between *N*-cyanoglycylglycine ethyl ester and ethanethiol in absence of acidic catalysts. Glycylglycine ethyl ester hydrochloride and potassium thiocyanate interacted in ethanol to give a compound, m. p. 105°, which behaved like the compound, m. p. 65°; it reverted to a dipeptide ester hydrohalide when treated with either dry hydrogen chloride in nitromethane or alkyl halides in hot ethanol.

Examination of the infrared spectra of the two compounds showed some remarkable features. In particular, the absorption in the 3 μ region was complex, and a strong band at about 2060 cm.$^{-1}$ was present. The latter was incompatible with structure (I; R = OEt), the only reasonable course being to attribute it to a thiocyanate ion (Miller and Wilkins, *Analyt. Chem.*, 1952, **24**, 1253). On this basis, these compounds would be glycine ethyl ester thiocyanate (II; R = OEt) and glycylglycine ethyl ester thiocyanate (II; R = NH·CH_2·CO_2Et) respectively. This interpretation is confirmed by the complex absorption in the 3 μ region, which is similar to that observed in these laboratories for other, similar amine salts, and by the development of a characteristic thiocyanate colour with ferric chloride solution. The thiocyanate ion was determined quantitatively by titration with silver nitrate. Further, it was found that these compounds were obtained from the reaction of potassium thiocyanate with either glycine ethyl ester hydrochloride or glycylglycine ethyl ester hydrochloride in warm ethanol for a few minutes, conditions which were unlikely to cause isomerisation to *N*-thiocarbamoyl derivatives. The failure of the above compounds to cyclise under acidic conditions and their behaviour towards alkyl halides is now readily explicable. Moreover, the toxicity of compound, m. p. 65°, towards rats and rabbits (Leonard, *Arch. intern. Pharmacodynamie*, 1929, **35**, 314) may possibly be attributed to the thiocyanate ion.

Authentic *N*-thiocarbamoylglycine ethyl ester (I; R = OEt) was obtained by esterification of *N*-thiocarbamoylglycine (I; R = OH) using either the azeotropic-distillation or the Fischer–Speier technique. Both the acid (I; R = OH) and the ester (I; R = OEt) had normal infrared spectra and readily cyclised to 2-thiohydantoin in aqueous hydrochloric acid. In fact, it was found necessary to exercise care during esterification in order to avoid formation of 2-thiohydantoin directly.

Johnson and Hemingway's interpretation (*J. Amer. Chem. Soc.*, 1916, **38**, 1550) of the reaction between ethyl *iso*thiocyanatoacetate (SCN·CH_2·CO_2Et) and ammonia, resulting in the formation of 2-thiohydantoin, is now questionable. It was suggested that intermediate formation of *N*-thiocarbamoylglycine ethyl ester (I; R = OEt) did not occur, but that the first product was *iso*thiocyanatoacetamide which then cyclised. We have found that *N*-thiocarbamoylglycine ethyl ester (I; R = OEt) is rapidly converted into 2-thiohydantoin in ethanolic ammonia so that any of the intermediates (I; R = OEt), (I; R = NH_2) or *iso*thiocyanatoacetamide may be involved in the reaction between ammonia and ethyl *iso*thiocyanatoacetate. It is felt, however, that in view of the reactivity of *iso*thiocyanates, *iso*thiocyanatoacetamide is the least likely of these.

Experimental

Infrared spectra were obtained on a Grubb-Parsons double-beam spectrometer. The solid specimens were prepared in potassium bromide discs.

Glycine Ethyl Ester Thiocyanate.—The reaction between equimolar quantities of potassium thiocyanate and glycine ethyl ester hydrochloride in refluxing ethanol during 4—5 hr. (Harries and Weiss, also Johnson, *locc. cit.*) afforded a product which was coloured and rather difficult to crystallise. When the solution of reactants was warmed for 5—20 minutes and then filtered, and ether was added to the filtrate, the *salt* (52%) crystallised readily; it had m. p. 65° (Found: C, 37·4; H, 6·3; N, 17·3. $C_5H_{10}O_2N_2S$ requires C, 37·0; H, 6·2; N, 17·3%). The infrared bands were at 3346 (s), 2963 (vs), 2608 (m), 2060 (vs), 1752 (vs), 1606 (m), 1505 (s), 1433 (s), 1420 (s), 1395 (m), 1330 (sh), 1306 (sh), 1255 (vs), 1110 (m), 1054 (m), 1013 (m), 907 (m), 859 (m) cm.$^{-1}$. This compound gave glycine ethyl ester hydrochloride, m. p. 142°, when treated with dry hydrogen chloride in nitromethane. Reaction with ethyl iodide, *iso*propyl bromide, or *n*-butyl iodide afforded the corresponding hydrohalide.

Glycylglycine Ethyl Ester Thiocyanate.—This *compound*, obtained from glycylglycine ethyl ester hydrochloride and potassium thiocyanate in a similar manner, had m. p. 105° (Found: C, 38·0; H, 5·9; N, 19·1; SCN^-, 25·7. $C_7H_{13}O_3N_3S$ requires C, 38·3; H, 6·0; N, 19·2; SCN^-, 26·5%) and the following infrared bands: 3380 (vs), 3140—2870 (vs, unresolved), 2720 (s), 2610 (s), 2530 (m), 2400 (w), 2060 (vs), 1740 (vs), 1644 (vs), 1577 (vs), 1493 (vs), 1468 (s), 1456 (s), 1430 (vs), 1413 (vs), 1383 (vs), 1355 (m), 1324 (m), 1304 (m), 1253—1232 (vs, unresolved), 1137 (m), 1114 (s), 1108 (s), 1100 (m), 1048 (m), 1025 (m), 1008 (s), 976 (w), 943 (w), 904 (s), 862 (m) $cm.^{-1}$. Treatment with dry hydrogen chloride in nitromethane or with alkyl halides afforded the corresponding peptide ester hydrohalide.

N-Cyanoglycylglycine Ethyl Ester.—A solution of glycylglycine ethyl ester (1·6 g.) in anhydrous dioxan (20 c.c.) was slowly added with stirring to a solution of freshly prepared cyanogen bromide (1·06 g.) in dioxan (20 c.c.) containing suspended sodium hydrogen carbonate (1·5 g.). The mixture was shaken at room temperature for 12 hr. and filtered. Evaporation of the filtrate under reduced pressure left an orange-yellow oil which crystallised under ether at 0°. Recrystallised from ethanol–ether, the *compound* (0·76 g.) had m. p. 82° (Found: C, 45·1; H, 5·8; N, 22·2. $C_7H_{11}O_3N_3$ requires C, 45·4; H, 6·0; N, 22·7%). It polymerised when kept. The residue from the first filtration was extracted with hot ethanol (50 c.c.) and filtered. On cooling, *glycylglycine ethyl ester hydrobromide* (0·74 g.), m. p. 182°, separated (Found: C, 30·2; H, 5·5; N, 11·7. $C_6H_{12}O_3N_2Br$ requires C, 29·9; H, 5·4; N, 11·6%).

Attempted Condensation of N-Cyanoglycylglycine Ethyl Ester with Ethanethiol.—*N*-Cyanoglycylglycine ethyl ester (200 mg.) was added to a solution of ethanethiol (70 mg.) in dry dioxan (10 c.c.), and the solution was saturated with dry hydrogen chloride at 0°. The solution was kept at room temperature for 12 hr. and evaporated. The residue (120 mg.), crystallised from ethanol, had m. p. 181°, undepressed on admixture with glycylglycine ethyl ester hydrochloride. *N*-Cyanoglycylglycine ethyl ester did not react with ethanethiol at temperatures up to 40° in up to 10 days in absence of acid catalyst.

N-Thiocarbamoylglycine.—2-Thiohydantoin (5·8 g.) was heated in a refluxing solution (200 c.c.) of hydrated barium hydroxide (15 g.) for 1 hr. (cf. Klason, *loc. cit.*). The solution was cooled and adjusted to pH 2 with dilute sulphuric acid, and barium sulphate was filtered off. The filtrate was continuously extracted with ether for 2 days and the *N*-thiocarbamoylglycine (2·7 g.), which separated from the ethereal solution, was twice recrystallised from ethanol, then having m. p. 179° (Found: C, 27·0; H, 4·4; N, 21·3; S, 23·7. Calc. for $C_3H_6O_2N_2S$: C, 26·9; H, 4·5; N, 20·9; S, 23·9%). Light absorption in 95% EtOH: $\lambda_{max.}$ 241 mμ. The infrared spectrum had the following bands: 3340 (vs), 3350 (vs), 3120 (vs), 2920 (s), 2780 (s), 2655 (s), 2555 (m), 1700 (vs), 1685 (sh), 1621 (vs), 1560 (vs), 1543 (vs), 1446 (s), 1416 (s), 1381 (s), 1361 (s), 1347 (s), 1290 (m), 1255 (vs), 1235 (sh), 1182 (s), 1043 (m), 962 (vs), 896 (m), 747 (m), 737 (m), 685 (m) $cm.^{-1}$. *N*-Thiocarbamoylglycine was warmed in 2N-hydrochloric acid and then kept overnight at room temperature; a quantitative yield of 2-thiohydantoin, m. p. 227—229° (decomp.), was obtained.

N-Thiocarbamoylglycine Ethyl Ester.—(i) *N*-Thiocarbamoylglycine (1 g.) was suspended in ethanol–benzene (50 c.c.; 1 : 1) containing toluene-*p*-sulphonic acid (0·1 g.). The solution was slowly distilled during 2 hr., more ethanol–benzene being added as required. Most of the solvent was removed under reduced pressure and the product was extracted into benzene (25 c.c.) and washed with 5% sodium hydrogen carbonate solution. The benzene was evaporated off and the *ester* (0·84 g.) crystallised from a little water, m. p. 78°.

(ii) A solution of *N*-thiocarbamoylglycine (1 g.) in ethanol (75 c.c.) at 0° was saturated with dry hydrogen chloride for 1 hr. The solution was shaken at room temperature for 12 hr., by which time the solution was homogeneous. Ethanol was removed under reduced pressure and the residual oil was dissolved in ethyl acetate (30 c.c.). After being washed with 5% sodium hydrogen carbonate, followed by water, the solution was evaporated under reduced pressure. The residue (0·97 g.), crystallised from water, had m. p. 79° (Found: C, 37·0; H, 6·1; N, 16·7; S, 19·5. $C_5H_{10}O_2N_2S$ requires C, 37·0; H, 6·2; N, 17·3; S, 19·8%). Light absorption in 95% EtOH: $\lambda_{max.}$ 241 mμ. The infrared spectrum had the following bands: 3414 (s), 3314 (s), 3200 (s), 3105 (w), 2984 (w), 2677 (vw), 1732 (vs), 1634 (vs), 1573 (s), 1446 (s), 1378 (s), 1356 (s), 1304 (m), 1256 (m), 1232—1217 (vs, unresolved), 1191 (sh), 1174 (sh), 1095 (w), 1045 (m), 1019 (m), 959 (s), 918 (vw), 863 (w), 758 (w), 739 (m), 712 (m) $cm.^{-1}$. The foregoing ester (0·8 g.) was dissolved in warm 2N-hydrochloric acid and kept at room temperature overnight. White prisms, m. p. and mixed m. p. 228—229° (decomp.), of 2-thiohydantoin (0·5 g.) were deposited. *N*-Thiocarbamoylglycine ethyl ester (50 mg.) was dissolved in saturated ethanolic ammonia (2 c.c.); after 3 hr. at room temperature, paper chromatography in butan-1-ol–water revealed

that all the ester had disappeared and that 2-thiohydantoin (R_F 0·54) and a trace of ultraviolet-absorbing material (R_F 0·28) were present. The solution was evaporated and the residue was crystallised from water (charcoal), affording 2-thiohydantoin (13 mg.), m. p. 222—224° (decomp.).

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Fungicidal Activity and Chemical Constitution. Part IV. Synthesis of* 5-n-*Alkyl*-8-*hydroxyquinolines.*

By D. WOODCOCK.

[Reprint Order No. 6630.]

Eleven new analogues of 8-hydroxyquinoline have been prepared in an attempt to improve the fungicidal activity.

THE antibacterial properties of 8-hydroxyquinoline ("oxine") and its derivatives are well known [see especially Albert *et al.*, Goldacre, and Balfour, *Brit. J. Exp. Path.*, **1947**, **28**, 69; 1950, **31**, 425; *Biochem. J.*, 1947, **41**, 534; *J.*, 1952, 4985; **1954**, 505; Shchukina and Savitskaya, *J. Gen. Chem.* (*U.S.S.R.*), 1952, **22**, 1218; Urbanski, Slopek, and Venulet, *Nature*, 1951, **169**, 29]. It is only recently that their fungicidal action has been examined: Mason (*Phytopathology*, **1948**, **38**, 740) tested eleven derivatives against *Stemphylium sarcinaeforme* and showed that chlorine or bromine in position 5 or 7 decreased the toxicity, but there has been no other systematic work.

The increase in fungistatic action due to long aliphatic side-chains in tetrahydroglyoxaline (Wellman and McCallan, *Contribn. Boyce Thompson Inst.*, **1946**, **14**, 151) and tetrahydropyrimidine (Rader, Monroe, and Whetstone, *Science*, 1952, **115**, 124) prompted the present work. Of the 5-*n*-alkyl-8-hydroxyquinolines only the methyl (Noelting and Trautmann, *Ber.*, 1890, **23**, 3654) and the propyl compound (Albert and Magrath, *Biochem. J.*, 1947, **41**, 534) have been previously prepared. The appropriate phenyl ester subjected to a Fries migration at 100—140° with anhydrous aluminium chloride gave a mixture of alkyl *o*- and *p*-hydroxyphenyl ketones separable by fractional distillation. Clemmensen reduction of the *para*-isomers gave the *p*-*n*-alkylphenols, the higher homologues often requiring prolonged treatment. Nitration of the *p*-*n*-alkylphenols in glacial acetic acid gave the 2-nitro-compounds, which were reduced in tetrahydrofuran in the presence of Raney nickel. In the final Skraup reaction arsenic pentoxide was the most successful of the oxidising agents used though the yields were poor throughout in contrast to those obtained by Vorozhtsov and Troshchenko [*J. Gen. Chem.* (*U.S.S.R.*), 1938, **8**, 431] for 8-hydroxy-5-phenyl- (95%) and by McMaster and Bruner (*J. Amer. Chem. Soc.*, **1935**, **57**, 1697) for 5-benzyl-8-hydroxy-quinoline (86%). The vulnerability of the lengthy alkyl substituent to the strong oxidising conditions present in the Skraup mixture which possibly accounts for the low yields appears to be even greater when a branched chain is present. Thus 2-amino-4-*tert.*-butylphenol gave only 8-hydroxyquinoline in a Skraup reaction with arsenic pentoxide though Coates, Cook, Heilbron, Hey, Lambert, and Lewis (*J.*, **1943**, 409) prepared 5-*tert.*-butyl-8-pyridylquinoline in a similar reaction by using sodium *m*-nitrobenzenesulphonate. Niederl (U.S.P. 2,483,838) reported the preparation of 8-hydroxy-5-(1 : 1 : 3 : 3-tetramethylbutyl)quinoline, m. p. 73°, from 2-amino-4-(1 : 1 : 3 : 3-tetramethylbutyl)phenol using picric acid, but this and various other oxidising agents in our hands gave only 8-hydroxyquinoline, m. p. 73°, as the final product.

The results of the biological testing by Dr. R. J. W. Byrde will be described elsewhere.

* Part III, *Ann. Appl. Biol.*, 1955, **44**, in the press.

Experimental

p-*Hydroxyphenyl Nonyl Ketone.*—The preparation of this compound, not previously described, exemplifies the conditions used in the Fries reaction. Phenyl decanoate [30 g.; prepared by heating phenol (12 g.) with decanoyl chloride (25 g.) until the evolution of hydrogen chloride ceased] was stirred at 110—120° (for higher ketones, 130—140°) during the gradual addition of powdered anhydrous aluminium chloride (18 g.), and then heated for a further 1 hr. After the addition of ice-cold hydrochloric acid, the product was extracted with ether, the ethereal solution washed with dilute hydrochloric acid and then water and dried, and the solvent removed. Distillation of the residue gave fractions, b. p. 150—160°/0·5 mm. and 160—200°/0·5 mm. Crystallisation of the latter from light petroleum (b. p. 60—80°) gave rhombic plates, m. p. 64—65° (Found: C, 77·6; H, 9·5. $C_{16}H_{24}O_2$ requires C, 77·4; H, 9·7%).

p-*Decylphenol.*—The above *ketone* (12·7 g.) was refluxed with amalgamated zinc (65 g.) and hydrochloric acid (65 ml.; *d* 1·16) for 48 hr., additional acid being added at 12-hourly intervals. On cooling, the product was extracted with ether, and the ethereal solution washed with dilute

4-n-*Alkyl*-2-*nitrophenols.*

Alkyl	Nitration temp.	M. p. or b. p.	Solvent	Found (%) C	H	N	Formula	Required (%) C	H	N
C_8H_{13}...	5—10°	135—140°/2 mm.	—	64·4	7·6	6·0	$C_{12}H_{17}O_3N$	64·6	7·6	6·3
C_8H_{17}...	10	32—33	B	67·3	8·4	5·5	$C_{14}H_{21}O_3N$	66·9	8·4	5·5
C_9H_{19}...	5—10	49—50	MeOH	67·9	8·5	5·3	$C_{15}H_{23}O_3N$	67·9	8·7	5·3
$C_{10}H_{21}$...	10	45—46	B	68·5	9·0	5·0	$C_{16}H_{25}O_3N$	68·8	9·0	5·0
$C_{12}H_{25}$...	10—20	55—56	MeOH	70·2	9·5	4·5	$C_{18}H_{29}O_3N$	70·35	9·4	4·6
$C_{14}H_{29}$...	10—20	62	MeOH	71·3	9·8	4·2	$C_{20}H_{33}O_3N$	71·6	9·9	4·2
$C_{18}H_{37}$...	30—40	72	MeOH	73·3	10·5	3·6	$C_{24}H_{41}O_3N$	73·7	10·5	3·6

B = light petroleum (b. p. 40—60°).

4-n-*Alkyl*-2-*aminophenols.*

Alkyl	M. p.	Solvent	Found (%) C	H	N	Formula	Required (%) C	H	N
C_4H_9	142—143°	A	69·8	8·0	10·2	$C_{10}H_{15}ON$	70·1	8·0	10·2
C_5H_{11}	135—136	A	73·9	9·4	7·8	$C_{11}H_{17}ON$	73·7	9·5	7·8
C_6H_{13}	136—137	Aq. MeOH	74·4	9·8	7·3	$C_{12}H_{19}ON$	74·6	9·8	7·25
C_7H_{15}	133—134	A	75·0	10·0	6·8	$C_{13}H_{21}ON$	75·4	10·1	6·8
C_8H_{17}	132—133	A	75·9	10·4	6·5	$C_{14}H_{23}ON$	76·0	10·4	6·3
C_8H_{17} * ...	131—132 †	MeOH	75·8	10·4	6·4				
C_9H_{19}	131—131·5	MeOH	76·4	10·3	6·0	$C_{15}H_{25}ON$	76·6	10·6	6·0
$C_{10}H_{21}$	129—130	A	77·1	10·9	5·8	$C_{16}H_{27}ON$	77·1	10·8	5·6
$C_{12}H_{25}$	125—126	MeOH	—	—	4·9	$C_{18}H_{31}ON$	78·0	11·2	5·05
$C_{14}H_{29}$	123	MeOH	78·4	11·7	4·6	$C_{20}H_{35}ON$	78·7	11·5	4·6
$C_{18}H_{37}$	119·5—120	MeOH	—	—	3·9	$C_{24}H_{43}ON$	79·8	11·9	3·9

A = ether–light petroleum (b. p. 40—60°).
* 1:1:3:3-Tetramethylbutyl.
† Niederl (*loc. cit.*) gives no m. p.

hydrochloric acid, water, and sodium hydrogen carbonate solution, and dried (Na_2SO_4). Removal of the solvent gave a solid which crystallised from light petroleum (b. p. 40—60°) in plates m. p. 57·5—58·5° (Found: C, 81·7; H, 11·1. Calc. for $C_{16}H_{26}O$: C, 82·0; H, 11·1%). Weitzel, Queckenstedt, Grellman, and Lautner (*Z. physiol. Chem.*, 1950, **285**, 58) give m. p. 54—55°. In the reduction of ketones of higher molecular weight, a little benzene was added to prevent the accumulation of solid in the condenser, and reduction was continued until a test portion of the product gave no red precipitate or colour with 2:4-dinitrophenylhydrazine.

Nitration of p-n-*Alkylphenols.*—(a) *Side chains up to* C_8. A solution of the phenol (1 g.) in glacial acetic acid (3 ml.) was stirred for 1 hr. at 5—10° during the dropwise addition of nitric acid (2 ml.; *d* 1·18). After dilution, the product was isolated with ether, and the extract washed with water and sodium hydrogen carbonate solution, and dried. The residue left after removal of the solvent was distilled *in vacuo*.

(b) *Side chains up to* C_{18}. Procedure was as in (a) except that glacial acetic acid (32 ml.) and nitric acid (4 ml.; *d* 1·18) were used and the optimum temperature was slightly higher. The

yellow crystalline product was collected, washed with water, dried, and recrystallised. Analytical details for new compounds are tabulated.

4-n-*Alkyl*-2-*aminophenols* (see Table).—A solution of the appropriate nitro-compound in the minimum amount of tetrahydrofuran required for solution was shaken in the presence of Raney nickel in hydrogen until uptake ceased. The product was isolated by removal of the solvent (after removal of the catalyst by centrifuging or filtration).

5-*Alkyl*-8-*hydroxyquinolines* (see Table).—The appropriate 4-*n*-alkyl-2-aminophenol (5 g.), concentrated sulphuric acid (10 ml.), and glycerol (5 ml.) were mixed and heated at 140—150° for 0·5 hr., then arsenic pentoxide (5 g.) was added and heating continued for a further 4 hr. The cooled mixture was diluted with water, excess of sodium carbonate added, and the crude product isolated by continuous extraction with chloroform. Evaporation of the chloroform left a dark brown viscous product which was purified by sublimation at 120°/0·5 mm., and then crystallised to constant m. p. The *hydrochlorides* were prepared by treating an ethereal solution of the base with dry hydrogen chloride and recrystallising the salt from ethyl alcohol–ether.

5-Alkyl-8-hydroxyquinolines.

			Found (%)				Required (%)			Hydrochloride	
Alkyl	M. p.	Solv.	C	H	N	Formula	C	H	N	M. p.	Found : Reqd. : Cl (%)
CH_3 *	121—122°	D	—	—	8·8	$C_{10}H_9ON$	75·5	5·7	8·8	280—282°	18·1 18·1
C_2H_5	105—106	MeOH	76·3	6·4	8·0	$C_{11}H_{11}ON$	76·3	6·4	8·1	270—280 (subl.)	16·9 16·9
C_3H_7 †	57—58	D	—	—	7·5	$C_{12}H_{13}ON$	77·0	7·0	7·5	245—246	15·9 15·9
C_4H_9	55—56	D	77·5	7·5	7·0	$C_{13}H_{15}ON$	77·6	7·5	7·0	211—212	15·2 15·0
C_5H_{11}	74—75	D	77·9	7·9	6·5	$C_{14}H_{17}ON$	78·1	7·9	6·5	242—243	14·4 14·1
C_6H_{13}	60—61	D	78·2	8·3	6·1	$C_{15}H_{19}ON$	78·6	8·3	6·1	228—230	13·3 13·4
C_7H_{15}	59—60	D	78·9	8·7	5·8	$C_{16}H_{21}ON$	79·0	8·6	5·8	228—230	12·9 12·7
C_8H_{17}	59—60	D	79·0	9·0	5·6	$C_{17}H_{23}ON$	79·4	8·9	5·5	—	— —
C_9H_{19}	62—62·5	D	79·6	9·3	5·4	$C_{18}H_{25}ON$	79·7	9·2	5·2	—	— —
$C_{10}H_{21}$	66—67	D	79·9	9·6	5·3	$C_{19}H_{27}ON$	80·0	9·5	4·9	—	— —
$C_{13}H_{25}$	74·5—75	MeOH	80·2	9·9	4·4	$C_{21}H_{31}ON$	80·5	9·9	4·5	—	— —
$C_{14}H_{29}$	82—83	C	80·9	10·1	4·0	$C_{23}H_{35}ON$	80·9	10·3	4·1	—	— —
$C_{16}H_{37}$	84·5—85·5	MeOH	81·5	10·8	3·9	$C_{27}H_{43}ON$	81·6	10·8	3·5	—	— —

C = methyl alcohol–acetone. D = aqueous methanol.
* Noelting and Trautmann (*loc. cit.*) give m. p. 122—124°.
† Albert and Magrath (*loc. cit.*) give m. p. 60—61°.

Attempted Preparation of 8-*Hydroxy*-5-(1 : 1 : 3 : 3-*tetramethylbutyl*)*quinoline.*—(*a*) Reaction as above, gave a sublimed product which after recrystallisation from aqueous methyl alcohol had m. p. 73—74°.

(*b*) A reaction as described by Niederl (*loc. cit.*) gave a sublimed product which after recrystallisation from aqueous methyl alcohol had m. p. 73—74° [Found (product from *a*) : C, 74·3; H, 4·7; N, 9·7; (product from *b*) C, 74·4; H, 4·8; N, 9·6. Calc. for C_9H_7ON : C, 74·5; H, 4·8; N, 9·65%]. Products from *a* and *b* both failed to depress the m. p. of 8-hydroxyquinoline.

Attempted Preparation of 5-tert.-*Butyl*-8-*hydroxyquinoline.*—The Skraup reaction with 2-amino-4-*tert.*-butylphenol was performed as described above; the sublimed product had m. p. 68—70°, raised by crystallisation from methyl alcohol to 73—74°, undepressed by 8-hydroxyquinoline (Found : C, 74·4; H, 4·8; N, 9·7%).

The author thanks Miss V. W. Rogers and Mrs. P. M. Pope for doing the experiments, Mr. J. F. Harris and Mr. D. R. Clifford for the nitrogen analyses, and Imperial Chemical Industries Limited for a gift of chemicals.

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Solvent Quenching of the Fluorescence of Anthracene.

By E. J. Bowen and K. West.

[Reprint Order No. 6461.]

The effect of temperature on the fluorescence efficiency of anthracene in a number of solvents has been measured. The changes observed are interpreted in terms of Mulliken-type interactions between excited solute and solvent molecules involving an element of A^-S^+ structure.

The effect of temperature on the fluorescence of solutions is still imperfectly understood. Rise of temperature may decrease or increase fluorescence intensity, and effects which are independent of concentration may be interpreted as van der Waals interactions with the solvent of the fluorescent molecules in either their ground or their excited states (Bowen and Coates, *J.*, 1947, 105; Bowen and Cook, *J.*, 1953, 3059). Measurements are here described relating to anthracene dissolved in several organic solvents, made over a wider range of temperature than so far recorded. The solutions were contained in small Dewar vessels, illuminated by 3650 Å radiation at one side, and the fluorescence measured at 90°. They were de-oxygenated and stirred by a fine stream of nitrogen and heated or cooled by a dipping copper rod along which heat was conducted when its upper end was either heated electrically or cooled with liquid oxygen. Temperatures were measured by a dipping thermocouple. The anthracene concentrations were about 10^{-4}M, and fixed at the point where the geometry of the apparatus gave a maximum measurable intensity. No great change in light absorption or band shape occurs over the temperature range studied, so that measurements could be directly converted into absolute quantum efficiencies by using the value of 0·24 for deoxygenated benzene solutions at ordinary temperature (Bowen and Williams, *Trans. Faraday Soc.*, 1939, **35**, 765).

The Figure shows graphically the variation of anthracene fluorescence with temperature for a number of solvents.* The curves show positive and negative temperature coefficients; toluene and *p*-xylene give maxima. Mixtures of solvents of opposite temperature coefficients also produce maxima (Bowen and Cook, *loc. cit.*). This lends support to the hypothesis that solvent quenching is a complex effect depending on the different positions of an excited solute molecule in the solvent cage and on detailed van der Waals interactions between different parts of the molecules.

Recent work on the fluorescence of phenols (Förster, *Z. Elektrochem.*, 1950, **54**, 42, 531; Mataga, Kaibe, and Korzumi, *Nature*, 1955, **175**, 721) has shown that the excited states are more acidic than the ground states, and that equilibration of excited states in van der Waals interaction with the solvent is rapid compared with the rate of fluorescence emission. If it is assumed that equilibration is also rapid for aromatic hydrocarbons, Bowen and Cook's kinetic scheme (*loc. cit.*) may be modified as follows:

$A + h\nu \longrightarrow A^*$		
$A^* + S \longrightarrow AS^1$		
$AS^1 \longrightarrow A + S + h\nu'$	k_f	
$AS^1 \longrightarrow A + S$	$k_1 \exp(-E_1/RT)$	
$AS^1 \rightleftharpoons AS^2$	$K \exp(Q/RT)$	
$AS^2 \longrightarrow A + S$	$k_2 \exp(-E_2/RT)$	
$AS^2 \longrightarrow A + S + h\nu'$	k_2	

where AS^1 and AS^2 are two rapidly interchanging modes of interaction of excited solute and solvent.

This scheme gives the fluorescence efficiency F equal to:

$$\frac{1}{(1 + k_a e^{-E_1/RT})(1 + Ke^{Q/RT})} + \frac{Ke^{Q/RT}}{(1 + k_b e^{-E_2/RT})(1 + Ke^{Q/RT})}$$

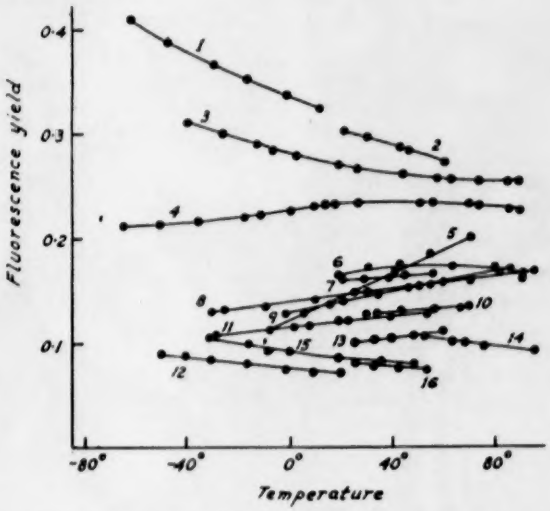
* In Tables 1 and 2 of Bowen and Cook (*loc. cit.*) the expression $F_0(1 - 10^{-4}\alpha l)$ should be corrected to $F_0 - 10^{-4}\alpha l$.

where $k_1/k_f = k_a$ and $k_2/k_3 = k_b$. The assumption of $K = 0$ leads to the equation

$$\log_{10}(1/F - 1) = \log_{10} k_a - E_1/4{\cdot}6T$$

Even for hexane solutions this simplified equation is not obeyed over the range of temperature studied.

There are too many unknown constants in the general equation to apply it fully to existing data, and its derivation is necessarily of a crude nature. Nevertheless, it is probably useful as a basis for interpreting the facts. It allows of both minima and maxima in fluorescence–temperature curves. Examples of the former are not known; they would be expected only at low temperatures.



Quantum yield–temperature curves for anthracene in various solvents.

1, Hexane
2, Acetic acid
3, Kerosene
4, Toluene
5, Diphenyl in toluene
6, *p*-Xylene
7, Pyridine
8, Chlorobenzene
9, Naphthalene in toluene
10, Dioxan
11, Thiophen
12, Triethylamine
13, Chloroform
14, Phenol
15, Mesitylene
16, 1-Chloronaphthalene

Anthracene vapour at about 300° has a fluorescence efficiency near unity (Bowen, *Trans. Faraday Soc.*, 1954, **50**, 97), and the problem arises of the nature of the degradation process in solution. The work of Porter and Windsor (*Discuss. Faraday Soc.*, 1954, **17**, 187) makes it clear that a large part, if not all, of such degradation proceeds *via* the triplet level. The electron spin reversal associated with a singlet–triplet change is most likely to be caused by an element of A^-S^+ structure in the interaction of the excited state with the solvent. The nature of such interactions has been explained by Mulliken (*J. Amer. Chem. Soc.*, 1952, **74**, 811). It is difficult to avoid this conclusion even for saturated paraffinic solvents. Those solvents which show reverse temperature coefficients of quenching of anthracene fluorescence are all of a Lewis-base nature. This, together with the well-known strong quenching of the fluorescence by aniline, indicates that in such solvents interactions with excited anthracene molecules are strong and that energy degradation is facilitated.

PHYSICAL CHEMISTRY LABORATORY, OXFORD UNIVERSITY. [*Received, May 24th*, 1955.]

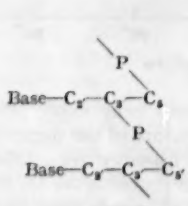
Nucleotides. Part XXXIV. The Hydrolysis of Dialkyl Esters of Uridine-3′ Phosphate and its Relevance to the Question of Phosphotriester Linkages in Ribonucleic Acids.*

By D. M. Brown, D. I. Magrath, and Sir Alexander R. Todd.

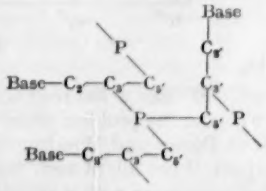
[Reprint Order No. 6569.]

Dimethyl and dibenzyl uridine-3′ phosphate have been prepared by the action of the corresponding diazoalkanes on uridine-3′ phosphate. In aqueous solvents they are unstable over the whole pH range, decomposing to a mixture of the monoesters of uridine-2′ and uridine-3′ phosphate together with traces of uridine-2′ : 3′ phosphate. It is considered from these findings that the occurrence of phosphotriester groupings in ribonucleic acids is unlikely.

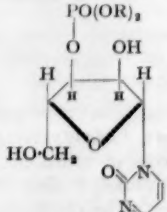
Earlier papers in this series have stressed the close analogy which exists between the hydrolytic behaviour of the monoalkyl esters of ribonucleoside-2′ and -3′ phosphates and that of the ribonucleic acids. The simplicity of the former compounds permitted a more precise study of the mechanism of their hydrolysis and this led to an acceptable structural hypothesis (Brown and Todd, *J.*, 1952, 52; 1953, 2040) in which the ribonucleic acids were formulated as polynucleotides (I), where the main chain was made up of nucleoside residues linked together in the 3′- and the 5′-positions by phosphodiester groups. Earlier, suggestions had been made that ribonucleic acids contained some phosphotriester linkages (Fletcher, Gulland, and Jordan, *J.*, 1944, 34); these suggestions rested on electrometric titration studies but no direct chemical evidence was adduced to support them. Such groupings if present would represent branching points in a polynucleotide chain such as (II). We pointed out (Brown and Todd, *J.*, 1952, 52) that a neutral triester group such as that present in (II) would be expected to be as readily hydrolysed as the normal internucleotidic linkage and hence, if present, would not affect the final composition of ribonucleic acid hydrolysates, but whether or not it did occur was left open.



(I)



(II)



(III)

In later work on the methylation of uridine-3′ phosphate (III; R = H) with methyl iodide and silver oxide (Brown, Magrath, and Todd, *J.*, 1954, 1442), intermediate products were observed which were considered to be neutral dimethyl esters (*e.g.*, III; R = Me); these products were surprisingly labile, being apparently converted into monomethyl esters in very weakly alkaline solution. In view of the fact that esters such as (III; R = Me) should be analogous in their behaviour to triester groups in polynucleotide structures such as (II) it was decided to study them more closely.

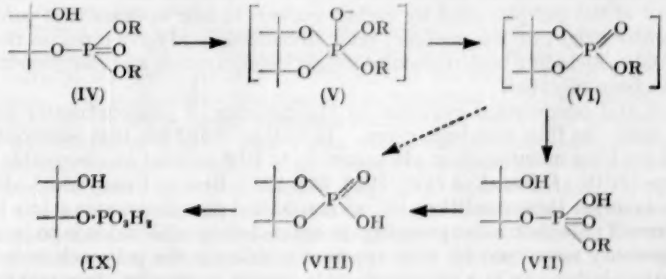
When uridine-3′ phosphate, dissolved in methanol, is treated with cold ethereal diazomethane until neutral, a crystalline uridine-3′ dimethyl phosphate (III; R = Me) is obtained. By using phenyldiazomethane the corresponding dibenzyl ester (III; R = CH_2Ph) is obtained as a gum from which final traces of phenyldiazomethane decomposition products are very difficult to remove. That the ester is essentially uridine-3′ dibenzyl phosphate follows from its smooth hydrogenolysis to uridine-3′ phosphate; this also demonstrates that no phosphoryl migration occurs during its preparation, and it can therefore be reasonably assumed that the substance obtained by using diazomethane is indeed

* Part XXXIII, *J.*, 1955, 2855.

(III; R = Me). The two esters behave as fast-running substances on paper chromatograms in the neutral propan-2-ol–water system. When chromatographed in the same system containing a little ammonia (pH 8—9) the compounds do not run as such, but as the monomethyl and monobenzyl esters respectively. A trace of the cyclic uridine-2′ : 3′ phosphate is also observed, but under these mildly alkaline conditions the hydrolysis which occurs leads almost exclusively to the monoesters. A qualitative study was made of the stability of the dimethyl ester at 37° over the pH range 0—9 in buffer solutions. Hydrolysis to the monomethyl ester and a small amount of cyclic phosphate occurred over the whole range (cf. Table 2 in Experimental section). At all pH values hydrolysis was complete in 16 hours. The half-life of the dimethyl ester was approximately 15 minutes at pH 0 and pH 9, and 75 minutes at pH 7. The ester showed maximum stability at pH 2—3 where it had a half life of 4—5 hours. At extreme pH values (*i.e.*, <2 and >11) further hydrolysis of the initially formed monomethyl ester and cyclic phosphate to free nucleotide became important; hydrolysis to uridine did not occur under any of the conditions studied.

The remarkable ease of hydrolysis of these dialkyl esters, especially under mildly alkaline conditions clearly indicates that the vicinal hydroxyl at $C_{(2')}$ is involved. Thus, in contrast, deoxyadenosine-5′ dibenzyl phosphate, which contains no vicinal hydroxyl group, can be prepared from its 3′-acetyl derivative by treatment with methanolic ammonia during 100 hours (Hayes, Michelson, and Todd *J.*, 1955, 808). The monoesters of uridine-2′ and uridine-3′ phosphate are not readily distinguishable by paper chromatography but when uridine-3′ dibenzyl phosphate is dissolved in the propan-2-ol–ammonia solvent and the solution set aside for some minutes the uridine benzyl phosphate produced can be shown by hydrogenation to be a mixture of approximately equal parts of the 2′- and the 3′-isomer. Additional evidence is provided by the action of ribonuclease on the hydrolysis product. This enzyme attacks esters of 3′- but not 2′-phosphates of the pyrimidine nucleosides (Brown and Todd *J.*, 1953, 2040); only half of the monobenzyl ester was converted into uridine phosphate, the rest being unaffected. A similar result was obtained with the uridine methyl phosphate obtained from uridine-3′ dimethyl phosphate under similar conditions; ribonuclease did not appear to have any action on the unhydrolysed dimethyl ester. There is thus very strong evidence that hydrolysis of the dialkyl to the monoalkyl esters is accompanied by phosphoryl migration.

In discussing the hydrolysis of monoesters (VII) of the 2′- and 3′-ribonucleotides with alkali or ribonuclease it was concluded (Brown and Todd, *loc. cit.*) that the mechanism involves a transesterification yielding the nucleoside-2′ : 3′ phosphate (VIII) which then breaks down to a mixture of the free 2′- and 3′-nucleotides (IX). Evidently the dialkyl esters undergo a similar form of alkaline hydrolysis but even more readily by virtue of their being neutral triesters. The conversion of the diester (IV) into the monoester (VII) must occur by a two-stage process if the oxygen of the vicinal hydroxyl enters into covalent linkage with the phosphorus, as the evidence of migration indicates. A possible mechanism is indicated below.



The first step would lead, perhaps *via* (V), to the cyclic triester (VI). Further hydrolysis of (VI) would be expected to proceed mainly by fission of a cyclic O–P bond giving the

monoester (VII) although a small amount of (VIII) might be formed directly by fission of the exocyclic O–P bond. This scheme accords with the observed products. No evidence for the occurrence of (VI) during the hydrolyses was found, but it might well be very unstable in view of the ready hydrolysis of the cyclic nucleoside-2′ : 3′ phosphates (VIII) compared with simple acyclic dialkyl phosphates (Brown and Todd, *J.*, 1952, 52). It may be recalled that Baddiley and Thain (*J.*, 1953, 903) noted a ready reaction between *cyclo*hexylamine and pantoyl-lactone-2 diphenyl phosphate, yielding the *cyclo*hexylamide of the 2 : 4-phosphate of pantothenic acid. This reaction, seemingly analogous to the conversion of (IV) into (VII) and (VIII), led to the cyclic phosphate rather than the acyclic monophenyl phosphate, presumably because of the greater stability of a six-membered as opposed to a five-membered cyclic phosphate ring (Baddiley and Thain, *J.*, 1952, 3783). A final decision on the mechanism of hydrolysis of the diesters must await quantitative kinetic studies.

Another point of some interest was noted during these investigations. Although alkylation with a diazoalkane is probably the best method for preparing the nucleoside dialkyl phosphates it was observed that when cytidine-2′ and -3′ phosphates were treated with trifluoroacetic anhydride, and anhydrous ethanolic ammonia added subsequently, a, mixture containing cytidine-2′ : 3′ phosphate and, apparently, cytidine diethyl phosphate was obtained. Although insufficient of the latter compound was obtained for full characterisation, its identity seems in little doubt since it underwent very ready hydrolysis (*e.g.*, in the propan-2-ol–ammonia solvent) to a substance chromatographically identical with cytidine-2′ (or -3′) ethyl phosphate. This observation suggests that the monoethyl ester isolated as a by-product in the preparation of cytidine-2′ : 3′ phosphate by the trifluoroacetic anhydride route (Brown, Magrath, and Todd, *J.*, 1952, 2708) may have originated from the diethyl ester, initially formed by a reaction between ethanol and a mixed anhydride of the type $(RO)PO(O{\cdot}CO{\cdot}CF_3)_2$.

It is pertinent to discuss the possibility of chain-branching in ribonucleic acids through triester linkages as in (II), in the light of the investigations reported in this paper. This type of branching was originally postulated in order to permit an unexpectedly high ratio of monoesterified to diesterified phosphate in a polynucleotide of high molecular weight, since in effect it increased the number of end groups in the molecule. Fletcher, Gulland, and Jordan (*loc. cit.*) found ratios up to 0·25 in their electrometric titration studies, and similar titration results have been reported by other workers using a variety of ribonucleic acid preparations (cf. Jordan, *Progr. Biophysics Biophys. Chem.*, 1951, **2**, 51). Other results seeming to support this postulate have come from studies on dye-binding and enzymic end-group assay but more recent reports have tended to minimise the proportion of monoesterified phosphate possibly because isolation techniques for ribonucleic acids have improved [for references see Jordan (*loc. cit.*); "The Nucleic Acids," Vol. I, p. 447, edited by Davidson and Chargaff, Academic Press, New York, 1955; Brown and Todd, *op. cit.*, p. 409]. Clearly the necessity or otherwise of invoking phosphotriester linkages on the basis of end-group assays by titration or by enzyme action must depend on the validity of molecular-weight determinations on the sample of ribonucleic acid used. Aside from the heterogeneity of the samples used by earlier workers it now appears that past estimates of the molecular weight of, for example, yeast ribonucleic acid have erred on the high side. No recent studies including both molecular-weight determination and electrometric titration seem to have been reported.

No direct and unequivocal evidence for the presence of phosphotriester groupings in ribonucleic acids has thus ever been given. It may be noted too that solutions of ribonucleic acids have been maintained at pH values up to 10·6 without an observable increase in acidic groups (Zittle, *J. Franklin Inst.*, 1946, **242**, 221; Brown, Fried, and Todd, *J.*, 1955, 2206) whereas under these conditions the uridine dialkyl phosphates are rapidly hydrolysed. If the presence of phosphotriester groupings in isolated ribonucleic acids is to be maintained it will be necessary to account for their apparent stability in the polynucleotide in contrast to their marked instability in a mononucleotide system. Since no abnormal behaviour of the phosphodiester linkages is observed in ribonucleic acids there seems no reason to suppose that any phosphotriester groupings would behave in an unexpected manner. In these circumstances unless and until some quite incontrovertible evidence is given for their

presence we prefer to assume that phosphotriester linkages do not exist in isolated ribonucleic acids. The presence or absence of triester branching in native nucleic acids within the living cell is a purely hypothetical question at the present time and is irrelevant to the discussion.

The experimental observations reported in this paper do not bear directly on the suggestions of Lee and Peacocke (*J.*, 1951, 3361) and of Cavalieri and Angelos (*J. Amer. Chem. Soc.*, 1950, **72**, 4686) that phosphotriester branching must be assumed to occur in deoxyribonucleic acids (cf. also Jordan, *loc. cit.*). Since no vicinal hydroxyl is present at $C_{(2')}$ in these acids any phosphotriester grouping in them should show the stability normally associated with a trialkyl phosphate. That trialkyl phosphates undergo ready hydrolysis to diesters is well known, so that in view of the well-recognised stability of deoxyribonucleic acids towards alkali it seems very unlikely that they could contain any phosphotriester groupings. The evidence bearing on this point has been discussed at greater length elsewhere (Brown and Todd, *Ann. Rev. Biochem.*, 1955, **24**, 311) but it may be noted here that Frick (*Biochim. Biophys. Acta*, 1952, **8**, 625) has found that treatment of a deoxyribonucleic acid with 0·1N-sodium hydroxide yields only traces of dialysable, ultraviolet-absorbing material; this argues strongly against the presence of short branches involving phosphotriester groups.

Experimental

Paper Chromatography of Uridine Phosphate Derivatives.—Two solvent systems were used throughout, *viz.*: A, propan-2-ol–water (70 : 30 v/v); B, propan-2-ol–water–ammonia (*d* 0·88) (70 : 25 : 5). The comparative R_P values of the materials studied in the two systems are recorded in Table 1. Spots were detected by photography in ultraviolet light and where necessary by spraying for phosphate. Substances were identified in all instances by comparison with authentic materials.

Table 1. *R_P values in solvent systems.*

Substance	A	B
Uridine-3′ phosphate	0·33	0·16
Dimethyl ester	0·76	—
Monomethyl ester	0·44	0·41
Dibenzyl ester	0·91	—
Monobenzyl ester	0·66	0·62
Uridine-2′ : 3′ phosphate	0·39	0·37

Uridine-3′ Dimethyl Phosphate.—Anhydrous uridine-3′ phosphate (0·1 g.) in dry methanol (3 c.c.), cooled in ice-water, was titrated to *ca.* pH 4 with ethereal diazomethane. A small amount of flocculent precipitate was removed and the solution was concentrated to small bulk, *in vacuo*, during which the product crystallised. A small amount of ethereal diazomethane was added to neutrality and, after addition of a little ether, the colourless needles of *uridine-3′ dimethyl phosphate* (0·066 g.), m. p. 147—148° with gas evolution, were collected and washed with ether. The substance was immediately transferred to a vacuum-desiccator for storage. It was very soluble in water (Found: C, 37·6; H, 4·85; N, 8·1. $C_{11}H_{17}O_9N_2P$ requires C, 37·6; H, 4·85; N, 8·0%).

Uridine-3′ Dibenzyl Phosphate.—Uridine-3′ phosphate (0·165) g.) was dissolved in methanol (3 c.c.), and a solution of phenyldiazomethane in ether added dropwise with cooling in an ice-bath. Addition was continued until the disappearance of red colour was slow. A small amount of amorphous material was removed at a centrifuge, and the clear solution evaporated under reduced pressure. The residual gum was dissolved in chloroform (5 c.c.) and the solution quickly washed with ice-cold sodium hydrogen carbonate solution and water, and then dried (Na_2SO_4). Removal of the chloroform *in vacuo* gave a gum which was triturated successively with ether (3 × 4 c.c.) and thiophen-free benzene (2 × 4 c.c.) and then dried at 30° over phosphoric oxide at 10^{-4}/mm. (Found: C, 56·6; H, 5·3; N, 5·45. $C_{23}H_{24}O_9N_2P$ requires C, 54·9; H, 4·7; N, 5·6%). The product was still contaminated with traces of phenyldiazomethane degradation products but was essentially the desired substance as shown by its reactions (below). The ether and the benzene extracts contained considerable quantities of the dibenzyl ester, contaminated with phenyldiazomethane degradation products.

The dibenzyl ester (200 mg.) in methanol (1 c.c.) was hydrogenated over a mixture (5 mg.) of palladium oxide and palladised charcoal. After 24 hr. paper chromatography showed that complete conversion into uridine phosphate had occurred. The solution was brought to pH 8

with dilute aqueous ammonia, and an aliquot part (containing 5 mg. of uridine phosphate) was run on to a column (1 × 10 cm.) of Dowex-2 resin (200—400 mesh; formate form) and the nucleotide eluted with sodium formate–formic acid buffer, as described earlier (Brown, Dekker, and Todd, *J.*, 1952, 2715). Only one peak was obtained corresponding in position (fraction 78) and optical density ratio (280/260 mμ, 0·33) to uridine-3′ phosphate.

Hydrolysis of Uridine-3′ Dibenzyl Phosphate.—The ester (25 mg.) was dissolved in a mixture (2 c.c.) of propan-2-ol, water, and ammonia (*d* 0·88) (70 : 25 : 5), set aside in the ice-chest overnight, and then evaporated to dryness *in vacuo*. The residue was shown by paper chromatography to consist of ammonium uridine benzyl phosphate with a trace of uridine-2′ : 3′ phosphate. The same result was observed on spotting the dibenzyl ester at the origin of a chromatogram and running in the ammoniacal solvent.

The ammonium salt (7·0 mg.) was hydrogenated in water (2 c.c.), and the nucleotide content of the solution examined by ion-exchange chromatography, as above. Two peaks of equal height corresponded to uridine-2′ and -3′ phosphate, demonstrating that the uridine benzyl phosphate was a mixture of approximately equal parts of the 2′- and 3′-isomers.

Another sample of the ammonium salt (3·6 mg.) in water (0·36 c.c.) was mixed with a solution (0·1 c.c.) of ribonuclease (10 mg./c.c.) and the pH of the solution was adjusted to 8·5 with very dilute aqueous ammonia (0·1 c.c.). After two days the solution was analysed on paper chromatograms. Only two spots were present, corresponding to uridine benzyl phosphate and uridine phosphate. Elution of the spots with 0·1N-hydrochloric acid (4 c.c.) and determination of the optical density of the solutions at 260 mμ gave the ratio, uridine phosphate : benzyl ester, 1·1. After 7 days no change in the amount of remaining benzyl ester had occurred. Added uridine-2′ : 3′ phosphate (2·1 mg.) was hydrolysed overnight to uridine-3′ phosphate, showing that the enzyme was still active.

Hydrolysis of Uridine-3′ Dimethyl Phosphate.—(a) *Propan-2-ol–water–ammonia.* It was initially observed that the methyl ester, when spotted on a chromatogram and run in the ammoniacal solvent, gave one spot corresponding to authentic uridine methyl phosphate (R_F 0·44; Brown, Magrath, and Todd, *loc. cit.*).

The dimethyl ester (2·0 mg.) was dissolved in the above solvent and set aside for several hr. at room temperature, the solution evaporated under reduced pressure, and phosphate buffer (0·2 c.c.; pH 7) containing ribonuclease (2·5 mg./c.c.) added. After incubation at 37° overnight the solution was chromatographed on paper. Two spots were present corresponding to uridine phosphate and unchanged methyl ester. These were present in about equal quantity (visually estimated). That the enzyme was still active was shown by its ability to convert added uridine-2′ : 3′ phosphate into uridine-3′ phosphate.

(b) *Buffer solutions.* The dimethyl ester (3 mg.) was dissolved in the following solutions (0·2 c.c.) : phosphate–citrate buffers (Vogel, "Quantitative Inorganic Analysis," Longmans Green and Company, London, 1951, p. 869) of pH 2·2, 3·0, 5·0, 7·0, in a standard buffer pH 9·0, and in 0·1N- and N-hydrochloric acid. The solutions were incubated at 37° and drops were removed at 0·25, 1·25, 4·25, and 16 hr. intervals. These were spotted on chromatograms which were run in solvent systems A and B. The results are collected in Table 2 where the symbols +, ++, and +++ refer to <10%, *ca.* 50% and >90% hydrolysis of uridine dimethyl phosphate, as judged visually from the intensity of the spots on photographs of the chromatograms in ultraviolet light. In the Table, pH 0 and 1 refer to the N- and 0·1N-hydrochloric acid solutions. In all cases the product of hydrolysis was uridine methyl phosphate together with some uridine-2′ : 3′ phosphate. Further hydrolysis to uridine phosphate occurred below pH 3.

TABLE 2. *Hydrolysis of uridine-3′ dimethyl phosphate.*

	pH						
Time (hr.)	0	1	2·2	3·0	5·0	7·0	9·0
0·25	++	+			+	+	++
1·25	+++	++	+	+	++	++	+++
4·25	+++	+++	+	++	+++		
16	+++	+++	+++	+++	+++	+++	+++

Action of Ribonuclease on Uridine-3′ Dimethyl Phosphate.—In view of the great lability of the triester it was impossible to work at the pH optimum of the enzyme (*ca.* pH 8). Massive amounts of the enzyme were therefore used at a low pH. The dimethyl ester (2·0 mg.) in phosphate–citrate buffer (0·2 c.c., pH 3 and 4) containing 5 mg. of enzyme per c.c., was kept at 18°, and drops were applied at intervals to chromatograms. Controls consisted of (1) solutions without the

enzyme and (2) uridine-2′ : 3′ phosphate (2·0 mg.) with and without enzyme. The rate of disappearance of the dimethyl ester was the same with and without enzyme although further degradation by the enzyme of the liberated monomethyl ester and cyclic phosphate (including cyclic phosphate added at the end of the experiment) was evident. That the enzyme was active at pH 3 was confirmed by the complete hydrolysis of uridine-2′ : 3′ phosphate in 5 hr. The experiment showed that the enzyme was not active against the dimethyl ester.

Action of Trifluoroacetic Anhydride on Cytidine-2′ (and -3′) Phosphate.–Anhydrous cytidylic acid (0·1 g.) and trifluoroacetic anhydride (0·6 c.c.) were shaken together. Dissolution was complete in 15 min. and next morning the excess of anhydride was removed *in vacuo* with the strict exclusion of moisture. The residual glass was treated with dry ethanolic ammonia and kept stoppered for 15 min. at 0°. The solid product, which consisted of *ca.* 70—80% of cytidine-2′ : 3′ phosphate, was removed at a centrifuge and discarded. The ethanolic solution was evaporated *in vacuo*, to give a gum. Paper chromatography in propan-2-ol–water showed it to consist of *ca.* 70% cytidine-2′ : 3′ phosphate together with a fast-running neutral material (R_F 0·72). The latter product was freed entirely from cyclic phosphate by chromatography on Whatman No. 3. paper, followed by elution with absolute ethanol of the relevant section of the paper. Insufficient material was isolated for characterisation (it appeared to crystallise in needles) but the substance evidently was cytidine diethyl phosphate since paper chromatography in the propan-2-ol–water–ammonia converted it entirely into a material having the same characteristics as cytidine ethyl phosphate (R_F 0·46) (Brown, Magrath, and Todd, *J.*, 1952, 2708).

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The Exchange of Oxygen between Alcohols and Water. Part II. The Acid-catalysed Reactions of* n-*Butyl Alcohol and* neo*Pentyl Alcohol.*

By I. DOSTROVSKY and F. S. KLEIN.

[Reprint Order No. 6575.]

The rates of the acid-catalysed oxygen exchange and decomposition of *n*-butyl alcohol and *neo*pentyl alcohol in aqueous media have been measured at 125°. The exchange reaction of *n*-butyl alcohol is some 3 times faster than its decomposition, while the exchange of *neo*pentyl alcohol is some 37 times slower than the decomposition. The decomposition of *n*-butyl alcohol is about 3 times slower than that of *neo*pentyl alcohol, the product being in both cases a rearranged alcohol, olefin, and ether. From these results and from data on the hydration of but-1-ene it is concluded that the exchange reactions proceed by a bimolecular attack of a solvent molecule on the conjugate acid of the alcohol. The same mechanism is probably correct also for other reactions of primary alcohols in acid media such as, for example, ether formation and halogenation. The decompositions proceed, on the other hand, through the initial formation of a carbonium ion by a unimolecular ionisation of the conjugate acid of the alcohol.

IN Part I * we reported that the oxygen exchange of *tert.*-butyl alcohol proceeds through the reversible formation of the carbonium ion. Kinetic measurements of the rates of the exchange and of olefin elimination reactions permitted the estimation of rates of carbonium-ion formation and the rate and activation energy of the decomposition of this ion to the olefin. In extending our work to other alcohols we have been guided by the consideration that primary and tertiary alcohols represent the two extremes in the behaviour of aliphatic alcohols. The study of representative alcohols from both classes should make it possible to infer the behaviour of other types of alcohol by interpolation.

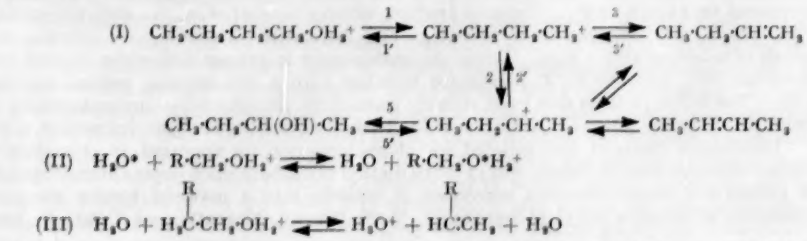
n-Butyl and *neo*pentyl alcohol undergo slow acid-catalysed decomposition when heated

* Part I, *J.*, 1955, 791.

in aqueous acidic media. The products from *n*-butyl alcohol are *sec.*-butyl alcohol, di-*n*-butyl ether, and a mixture of butenes. *neo*Pentyl alcohol decomposes to *tert.*-pentyl alcohol and a mixture of pentenes. Polymerisation of the olefins may also occur.

Since both decomposition and exchange are acid-catalysed they probably involve, as a common step, the reversible and rapid formation of the conjugate acid of the alcohol, the oxonium ion: $ROH + H_3O^+ \rightleftharpoons ROH_2^+ + H_2O$.

The subsequent reactions of the oxonium compound by one or more of the possible mechanisms detailed below may lead to the exchange and to the formation of the various decomposition products.



Oxygen exchange can occur by reactions 1 and 1′ of scheme (I), the recombination of the *n*-butyl ion with water, and by mechanisms (II) and (III). Olefins can be formed by schemes (I) and (III), and *sec.*-butyl alcohol may be formed by reaction 5 of scheme (I), and possibly by mechanism (III). Ethers may be formed by mechanisms 1′ and 5 of scheme (I) and by schemes (II) and (III).

The correct and unambiguous assignment of the various pathways cannot be made on the basis of the study of the exchange reaction of *n*-butyl alcohol alone. Additional evidence was obtained from the study, in sealed tubes at 125°, of the oxygen exchange of *neo* pentyl alcohol, from the rate of decomposition of both *n*-butyl alcohol and *neo*pentyl alcohol, and from the hydration of but-1-ene. Solutions of the alcohols were made up in aqueous sulphuric acid (*ca.* 1N). The medium was enriched with ^{18}O in the exchange reactions, and was of normal isotopic composition in the decomposition. Otherwise conditions were identical for the two reactions. The kinetics of the exchange reactions were followed by observing the increase in the ^{18}O-enrichment of the undecomposed alcohol as a function of time. Since the alcohols produced in the decomposition, *sec.*-butyl alcohol and *tert.*-pentyl alcohol, exchange oxygen rapidly under our conditions, they will have the isotopic composition of the medium. To avoid errors from the presence of these materials in the final samples it was necessary to adopt a careful and elaborate purification and decontamination technique before subjecting the samples to isotopic analysis.

The kinetics of the total decomposition were followed by estimating the amount of alcohol remaining unchanged as a function of time. The analysis was made by the isotopic dilution technique. Known amounts of enriched alcohol were added to samples of the reaction mixture, the alcohol was separated and purified, and its isotopic composition determined. From the amount and composition of the added tracer and the composition of the isolated alcohol the amount of unchanged alcohol originally present was calculated.

The rates of the exchange and decomposition reactions for both alcohols are presented in Table 1.

The mechanistic interpretation of the observed rate of decomposition of *n*-butyl alcohol can be derived from a comparison with the similar reaction of *neo*pentyl alcohol. The rearrangement of the *neo*pentyl skeleton is known to follow immediately upon the formation of the carbonium ion (cf. Ingold, "Structure and Mechanism in Organic Chemistry," Cornell Univ. Press, 1953, p. 511 *et seq.*). The decomposition of *neo*pentyl alcohol in acidic media is, therefore, almost irreversible and its rate measures the rate of heterolysis of the oxonium ion.* Measurements in formic acid solutions have shown that the rate of ionisation

* In the present paper, the heterolysis of the oxonium compound is taken to mean the reaction: $-C-CH_2^+ \longrightarrow -C^+ + H_2O$ and not the reaction involving the splitting of hydrogen.

of *neo*pentyl bromide to give carbonium ions is typical of all primary aliphatic bromides (Dostrovsky and Hughes, *J.*, 1946, 171). From theoretical considerations, involving the operation of the inductive effect, this rate of ionisation of *neo*pentyl compounds should be somewhat higher than that of analogous *n*-alkyl compounds. The same relationship is

TABLE 1. *Rate constants for the exchange and decomposition of* n-*butyl alcohol and* neo*pentyl alcohol in aqueous acid at* 125°.

Alcohol	Normality of sulphuric acid	10^5k (sec.$^{-1}$) Exchange	Decomp.
n-Butyl	0·917	56	16·4
n-Butyl	0·092	7	—
*neo*Pentyl	0·960	1·4	51

probably maintained with respect to heterolysis in aqueous media of the oxonium compounds. We conclude, therefore, that the rate of heterolysis of the oxonium compound of *n*-butyl alcohol will be equal to or somewhat smaller than that of *neo*pentyl alcohol. The observed rate constants (Table 1) are not the true constants of the various reactions summarised in schemes (I)—(III) but are composite rate coefficients having the form: $k_{obs.} = kK[H^+]$, where K is the equilibrium constant defined by $K = [ROH_2^+]/([ROH][H^+])$. Since values of K for the various alcohols are not available, it is difficult to compare the true rate constants for two alcohols in terms of the observed rate constants. However, for the primary alcohols under discussion it is not likely that the values of K differ greatly. It may be expected further than the difference, if any, will be in the direction of a higher value of K for *neo*pentyl alcohol (*i.e.*, this alcohol will be slightly more basic than *n*-butyl alcohol).

Turning now to the data of Table 1 we see that the decomposition of *n*-butyl alcohol is some three times slower than that of *neo*pentyl alcohol, a factor which may be easily accounted for by the expected differences in rates of heterolysis of the oxonium compounds and the values of K. This indicates, not only that the decomposition of *n*-butyl alcohol is a consequence of such an ionisation, but also that the contribution of the reaction of scheme (III), *i.e.*, β-olefin elimination, is negligible. It follows further that the reverse reaction 1′ in scheme (I) cannot be appreciable as compared with reaction 1, or the rate of disappearance of *n*-butyl alcohol would have been much smaller than that of *neo*pentyl alcohol.

The fact that oxygen exchange in *n*-butyl alcohol is faster than the decomposition would mean that at least part of the reaction proceeds by another mechanism, probably the bimolecular one shown in scheme (II). The final decision as to the extent of exchange contributed by (I) and (II) can only be made if more precise information is available regarding the reversibility of the ionisation of the oxonium compound, the first step of scheme (I). To this end we have studied the hydration of [^{14}C]but-1-ene under the conditions of our exchange experiments (Dostrovsky and Klein, to be published). Both but-1-ene and but-2-ene are formed in the acid decomposition of *n*-butyl alcohol but but-2-ene is known to be hydrated solely to *sec.*-butyl alcohol. The composition of the products formed by the hydration of [^{14}C]but-1-ene were determined by examining the radioactivity of the alcohols produced. The radioactive but-1-ene was sealed in tubes together with aqueous sulphuric acid and heated at a temperature and for times identical with those used in the exchange reactions. The analysis of the products of hydration was made by adding both *n*- and *sec.*-butyl alcohol carriers to the mixture after reaction. After elaborate separation and decontamination it was found that the amount of *n*-butyl alcohol formed on hydration of but-1-ene is not more than 1 part in 1000 of the hydrated product. The dehydration of the normal alcohol is, therefore, essentially irreversible. This result is a consequence of the minute proportion of the primary carbonium ion present in equilibrium with the secondary ion and not because of any inherent slowness of the reaction of the first ion with water.

The essential irreversibility of the first step precludes the participation of this

mechanism in the oxygen-exchange reaction. We may, therefore, conclude that oxygen exchange proceeds almost entirely by the bimolecular reaction scheme (II).

A check of this conclusion may again be obtained by reference to the results of the oxygen exchange of *neo*pentyl alcohol. Dostrovsky, Hughes, and Ingold (*J.*, 1946, 173) have shown that steric hindrance causes *neo*pentyl compounds to be particularly resistant to bimolecular attack on the α-carbon atom. If oxygen exchange of primary alcohols proceeds by a bimolecular attack on the α-carbon of the oxonium compound we should find that the rate of exchange of *neo*pentyl alcohol is greatly suppressed compared with that of a normal alcohol. Table 1 shows that this is so, *neo*pentyl alcohol exchanging at least 37 times slower than *n*-butyl alcohol, thus supporting the bimolecular mechanism (II). While this depression of the rate of exchange of *neo*pentyl alcohol is considerable, analogy with the corresponding bromides (Dostrovsky and Hughes, *loc. cit.*) would have predicted a much greater effect. It is possible that some of the observed exchange of this alcohol is due to a unimolecular reaction. This point is now being investigated further. Since the reacting entity is the oxonium compound and not the free alcohol the observed rate coefficient is composite and includes the concentration (or, better, the activity) of hydrogen ion and the equilibrium constant for the formation of the oxonium compound.

$$k_{obs.}(\text{exchange}) = k_2K[H^+]$$

As the value of the equilibrium constant K is unknown it is impossible to estimate the true bimolecular rate constant k_2. Similarly for the unimolecular ionisation of *neo*pentyl and *n*-butyl oxonium compounds the rate of decomposition of the alcohol is given by $k_{obs.}(\text{decomp.}) = k_1K[H^+]$ and here again we cannot find the value of k_1. Therefore the rates of ionisation and of bimolecular reactions of oxonium compounds cannot be compared with the rates of similar reactions of the corresponding bromides and sulphonium compounds.

The conclusions regarding the mechanism of the exchange reaction are applicable to other acid-catalysed reactions in aqueous media. For example, the acid-catalysed formation of *n*-alkyl ethers may now be assumed to proceed by the bimolecular attack of an alcohol molecule on the oxonium compound. From the quantities of ether formed (essentially an irreversible reaction in our conditions) compared with the exchange reaction, it appears that *n*-butyl alcohol is a somewhat more effective nucleophilic reagent than water. An analogous conclusion regarding the relative nucleophilic reactivity of ethanol and water was derived from the study of the solvolytic reactions of the phosphorochloridates (Dostrovsky and Halmann, *J.*, 1953, 505).

The halogenation of alcohols by the halogen acids provides another example. Our results confirm the conclusion of Grunwald and Winstein (*J. Amer. Chem. Soc.*, 1947, **69**, 2051) regarding the mechanism of the bromination of ethyl alcohol by hydrogen bromide, the proof of which has been inconclusive (cf. Ingold, *op. cit.*, p. 340).

Experimental

neo*Pentyl Alcohol.*—Ethyl trimethylacetate (18 g.) in dry ether (60 ml.) was added dropwise to a suspension of lithium aluminium hydride (30 g.) in ether (70 ml.). After the excess of hydride had been decomposed with water–alcohol–ether the solution was poured on ice–sulphuric acid and the *neo*pentyl alcohol was isolated as usual. It was fractionated through a 20-plate column (yield 60%, m. p. 54·9°; purity, estimated from freezing-point depression, better than 99·6%).

neo*Pentyl* [^{18}O]*Alcohol.*—Trimethylacetic acid was allowed to exchange with ^{18}O-enriched water by heating them in a sealed tube to 70° for 5 days with occasional shaking. The enriched acid obtained was esterified with ethyl alcohol, sulphuric acid being used as catalyst. The ester was reduced to the alcohol as described above. The product contained 1·23 mol.% of *neo*pentyl [^{18}O]alcohol.

n-*Butyl* [^{18}O]*Alcohol.*—Sodium *n*-butyl sulphate (38 g.) was added to 10N-sodium hydroxide solution (30 ml.) enriched in ^{18}O. The mixture was refluxed for 2 days in an apparatus arranged for continuous removal of the alcohol–water azeotrope. The azeotrope was saturated with

anhydrous potassium carbonate and the alcoholic layer dried and fractionated through a 20-plate column (b. p. 116—117°, 5·62 mol.% of *n*-butyl [^{18}O]alcohol).

sec.-Butyl [^{18}O]alcohol was prepared by the lithium aluminium hydride reduction of ethyl methyl ketone which had previously been allowed to exchange with ^{18}O-enriched water. It had b. p. 99·1—99·5°, 5·3 mol.% of *sec.*-butyl [^{18}O]alcohol.

Exchange Reaction of n-*Butyl Alcohol.*—Portions (55 ml.) of a solution of *n*-butyl alcohol (0·729M) in aqueous sulphuric acid (0·917N) enriched in ^{18}O (2·58 atom %) were vacuum-sealed in glass tubes and placed in an oil thermostat at 125° ± 0·2°. Tubes were withdrawn at intervals, chilled, and opened. The small upper layer (containing about 75% of di-*n*-butyl ether and 25% of *n*-butyl alcohol) was removed and the aqueous layer neutralised with 10N-potassium hydroxide solution enriched to 2·58 atom % with respect to ^{18}O. The solution was fractionally distilled and the azeotrope collected. The upper layer of the distillate was separated and the aqueous layer saturated with potassium carbonate to salt out more alcohol. The combined alcoholic layer was dried (K_2CO_3) and fractionally distilled. When the temperature at the top of the column reached the b. p. of *n*-butyl alcohol the distillation was interrupted and pure *sec.*-butyl alcohol (0·5 ml.) was added to the top of the column and allowed to flow into the flask. The distillation was resumed and continued until the b. p. of the pure normal alcohol was again reached. Separate experiments using *sec.*-butyl [^{18}O]alcohol and *n*-butyl alcohol showed that the fractionation alone left about 0·5% of the secondary alcohol in the *n*-butyl alcohol and after the decontamination with added *sec.*-butyl alcohol no trace of the *sec.*-butyl [^{18}O]alcohol could be detected.

The purified *n*-butyl alcohol was fractionated and the various fractions analysed for ^{18}O by Anbar, Dostrovsky, Klein, and Samuel's procedure (*J.*, 1955, 155). The constancy of the ^{18}O content of the various fractions confirmed the completeness of the decontamination from *sec.*-butyl [^{18}O]alcohol. A typical run is shown in Table 2. The values of N represent mole fractions of labelled alcohol. The rate constant was calculated by the method of least squares.

Decomposition of n-*Butyl Alcohol.*—Solutions of *n*-butyl alcohol in aqueous sulphuric acid were made up as in the previous experiment, except that all materials had normal isotopic compositions and were sealed in tubes. The tubes were placed in the thermostat together with

TABLE 2. *Exchange of* ^{18}O *between* n-*butyl alcohol* (0·729M) *and water in the presence of sulphuric acid* (0·917N) *at* 125·0°.

Time (days)	0	2	4	6	8	12	18	18	24	∞
10^3N_t	0·40	1·085	1·76	2·105	2·195	2·825	3·31	3·285	3·54	4·841
$\log (N_\infty - N_0)/(N_\infty - N_t)$	—	0·0725	0·1585	0·1965	0·2250	0·3430	0·4625	0·4555	0·5335	—

$k_{obs.}$ (exchange) = 0·56 × 10^{-6} sec.$^{-1}$.

the tubes used in the exchange experiments. After removal from the thermostat the tubes were chilled and opened, and to 50 ml. of the solution was added 0·300 ml. (3·28 mol.) of *n*-butyl [^{18}O]alcohol (5·62 mol. % ^{18}O). The rest of the procedure was identical with that used in the exchange experiments except that the decontamination step with *sec.*-butyl alcohol was omitted. The ^{18}O-content of the resulting butyl alcohol was used in calculating the percentage of the alcohol decomposed, by use of the isotopic dilution formula :

$$\text{Fraction undecomposed} = f = [(N-N_t)(N_0-N_\infty)]/[(N_t-N_\infty)(N-N_0)]$$

where N and N_∞ are the mole fraction of butyl [^{18}O]alcohol in the tracer and normal *n*-butyl alcohol, and N_t and N_0 are similar quantities measured at times t and 0 respectively. The rate coefficient for the decomposition reaction was calculated, first-order kinetics being assumed, from the equation $kt = 2{\cdot}303 \log 1/f$. A typical run is shown in Table 3.

TABLE 3. *Decomposition of* n-*butyl alcohol* (0·729M) *in aqueous sulphuric acid* (0·917N) *at* 125·0°.

$N_t = 0{\cdot}0020$; $N_\infty = 0{\cdot}04198$.

Time (days)	0	12	18	24	36
10^3N_t	0·566	0·602	0·669	0·686	0·761
f	—	0·902	0·758	0·728	0·617
$\log 1/f$	—	0·0448	0·1203	0·1379	0·2097

$k = 0{\cdot}16 \times 10^{-6}$ sec.$^{-1}$ (by least squares).

Exchange Reaction of neo*Pentyl Alcohol.*—Portions (55 ml.) of a solution of *neo*pentyl alcohol (0·242M) in aqueous sulphuric acid (0·960N) enriched in ^{18}O were vacuum-sealed in glass tubes

and heated in an oil-thermostat at 125°. At intervals the tubes were withdrawn and treated as described for *n*-butyl alcohol. The crude *neo*pentyl alcohol was purified as follows: Concentrated hydrochloric acid (10 ml.) was added to the dry alcohol and after being thoroughly shaken was allowed to stand. The upper layer (containing mainly *tert.*-pentyl chloride) was removed, the aqueous layer diluted with 2 volumes of water, and the alcohol distilled off. The upper alcoholic layer was dried (K_2CO_3) then fractionally distilled. Several fractions boiling at the same temperature (118°) were collected and analysed for ^{18}O content. The constancy of the isotopic composition of the various fraction indicated the purity of the alcohol.

The efficiency of the purification procedure was tested in the following experiment: *tert.*-Pentyl alcohol (2 ml.) was dissolved in ^{18}O-enriched water (10 ml.; 9·4 atom % $H_2{}^{18}O$) to which concentrated sulphuric acid (0·25 ml.) had been added. The mixture was heated at 55° with frequent shaking for 4 hr; this time is sufficient for the complete exchange of oxygen between *tert.*-pentyl alcohol and water. *neo*Pentyl alcohol (2 g.) was then added and the mixture subjected to the purification described above. In the step involving concentrated hydrochloric

TABLE 4. *Exchange of* ^{18}O *between* neo*pentyl alcohol* (0·242M) *and water in the presence of sulphuric ocid* (0·960N) *at* 125°.

Time (days)	0	18	30	∞
10^3N_t	0·200	0·253	0·279	2·500
$\log [(N_\infty - N_0)/(N_\infty - N_t)]$	—	0·0101	0·0152	—

$k_{obs.}$ (exchange) = $1·4 \times 10^{-6}$ sec.$^{-1}$.

acid, material enriched in ^{18}O was used (7 atom % ^{18}O) and the dilution was made with 2·5 atom % $H_2{}^{18}O$. The *neo*pentyl alcohol recovered was analysed and found to contain 0·00023 atom % excess of ^{18}O. The maximum error introduced in the kinetic runs by the purification procedure is, therefore, not more than 3%. A typical exchange run is presented in Table 4. In a duplicate run a value of $1·3 \times 10^{-6}$ sec.$^{-1}$ was obtained.

Decomposition of neo*Pentyl Alcohol.*—The procedure was identical with that described for the exchange reaction, except that materials of normal isotopic composition were used. The amount of undecomposed *neo*pentyl alcohol was determined by the isotopic dilution technique using ^{18}O-labelled *neo*pentyl alcohol. A typical run is shown in Table 5.

TABLE 5. *Decomposition of* neo*pentyl alcohol* (0·242M) *in aqueous sulphuric acid* (0·960N) *at* 125°.

$N_t = 0·0020$. $N_\infty = 0·01227$.

Time(days)	0	12	18
Tracer added (mg./50 ml.)	433	141	109
10^3N_t	0·371	0·390	0·389
f	—	0·588	0·453
$\log 1/f$	—	0·2306	0·3439

$k_{obs.}$ (decomp.) = $0·51 \times 10^{-6}$ sec.$^{-1}$.

Formation of Ether in the Reactions of n*-Butyl Alcohol.*—The ether layer formed in some of the reaction tubes during the exchange and decomposition runs was separated and weighed. The partition coefficient of *n*-butyl alcohol between di-*n*-butyl ether and aqueous sulphuric was determined in separate experiments to be 5 at room temperature. This value was used in correcting the weight of the ether isolated for dissolved alcohol. The corrected values are: 2·6 mmols. per 50 ml. after 18 days and 3·7 mmols. per 50 ml. after 24 days. A linear increase in ether formation with time being assumed, the approximate rate constant of 6×10^{-8} l. mole^{-1} sec.$^{-1}$ was found. Since the rate of exchange under these conditions is about 1×10^{-6} l. mole^{-1} sec.$^{-1}$, the ratio of the rate of ether formation to the rate of exchange is about 6.

Composition of Olefin produced in the Reactions of n*-Butyl Alcohol.*—The gas produced in some of the reaction tubes was analysed mass-spectrometrically and found to contain but-1-ene and but-2-ene in the ratio 1 : 10.

We thank Mr. M. Feld for numerous mass spectrometric analyses and Dr. D. Samuel for the samples of *neo*pentyl [^{18}O]alcohol.

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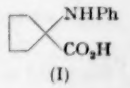
Studies in Pyrolysis. Part V. Pyrolysis of* 1-*Anilino*cyclo-*alkanecarboxylic Acids.*

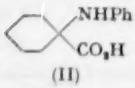
By W. C. Bain and P. D. Ritchie.

[Reprint Order No. 6576.]

1-Anilino*cyclo*pentanecarboxylic acid, pyrolysed in the liquid phase (*ca.* 250°), yields not only aniline, water, and 1-(1-hydroxy*cyclo*pentanecarboxyanilido)*cyclo*pentanecarboxylic lactone (cf. Plant and Facer, *J.*, 1925, **127**, 2037), but also *cyclo*pent-1-enecarboxylic acid and 1-hydroxy*cyclo*pentanecarboxyanilide. Precisely parallel qualitative results are given by the homologous 1-anilino-*cyclo*hexane- and -*cyclo*heptane-carboxylic acids; the yield of olefinic acid increases, and that of lactone decreases, as the size of the *cyclo*alkane ring is increased. Reasons are adduced for believing that the hydroxy-anilides arise by primary thermal rearrangement of the isomeric parent anilino-acids rather than by secondary reactions of the primary products. In the gaseous phase (*ca.* 500—550°) all the above products are very largely decomposed, with formation of much carbon monoxide and dioxide.

Recent studies on the pyrolysis of a series of homologous 1-anilino*cyclo*alkanecarboxylic acids (I—III), and of the corresponding 1-anilino-1-cyano*cyclo*alkanes, have removed a number of apparent anomalies from the literature and brought to light some novel reactions. The present paper deals with the anilino-acids; the cyano-compounds will be dealt with in a future communication.


(I)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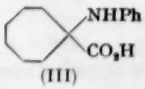
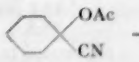

(III)

During a previous search for new general routes to polymerisable substituted olefins, of the acrylic and related types, it was found that vapour-phase pyrolysis (*ca.* 450—550°) of α-acyloxy-esters (*e.g.*, IV) and acylated cyanohydrins (*e.g.*, V) leads in general to smooth elimination of carboxylic acid, with formation of the desired olefinic ester (*e.g.*, VI) or nitrile (*e.g.*, VII) respectively (Burns, Jones, and Ritchie, *J.*, 1935, **400**, **714**; Ritchie, *J.*, 1935, **1054**; Ritchie, Jones, Burns, and I.C.I., B.P. 425,885, U.S.P. 2,183,357, 2,265,184):

(IV) $BzO{\cdot}CMe_2{\cdot}CO_2Me \longrightarrow BzOH + CH_2{:}CMe{\cdot}CO_2Me$ (VI)

(V)  (VII)

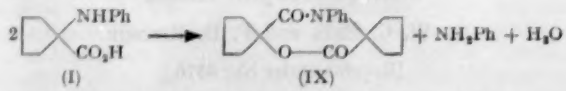
The method fails, however, when applied to α-acyloxy-acids (*e.g.*, VIII), which break down thermally by a more complex route and do not yield olefinic acids (Bagard, *Bull. Soc. chim. France*, 1907, **1**, 307):

(VIII) $AcO{\cdot}CHR{\cdot}CO_2H \longrightarrow AcOH + CO + R{\cdot}CHO$

Nevertheless, it is recorded that the anilino-acid (II) breaks down, on distillation, to aniline and *cyclo*hex-1-enecarboxylic acid (Betts, Muspratt, and Plant, *J.*, 1927, 1310), which suggests that pyrolysis of suitable anilino- instead of acyloxy-compounds might provide a simple alternative route to olefinic acids, and perhaps to all the desired types of olefinic monomers. The possibility is attractive in view of the ready accessibility of many *x*-anilino-*x*-cyanoalkanes as a starting point (cf. Mulder, *Rec. Trav. chim.*, 1907, **26**, 180). Some complications seem likely, however. For example, the anilino-acid (I) is reported (Plant and Facer, *J.*, 1925, **127**, 2037) to break down thermally in quite a

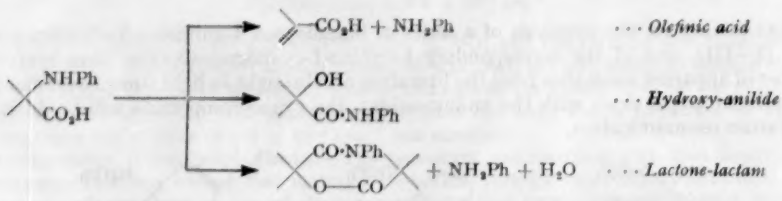
* Part IV, *J.*, 1955, 2717.

different way, yielding the curious " lactone-lactam " (IX), which suggests that the size of the *cyclo*alkane ring exerts some specific controlling influence on the degradation route.



Further, certain α-anilino-acids, on pyrolysis follow two competitive routes, dehydration to a dioxopiperazine and decarboxylation to an amine (cf. Hurd, " The Pyrolysis of Carbon Compounds," Chemical Catalog Co., New York, 1929, Chap. 15), so that interference by these routes might be expected.

For all these reasons, pyrolysis of the anilino-acids (I—III) merited detailed study; and the present work has now shown that the influence of ring size is merely quantitative. All three acids show precisely the same qualitative type of breakdown in the liquid phase at *ca.* 250° in a static reaction vessel (see Experimental section), yielding, not only aniline, water, olefinic acid, and lactone-lactam, but also a wholly unexpected minor product, the 1-hydroxy*cyclo*alkanecarboxyanilide isomeric with the parent anilino-acid. The results can be represented by the following generalised scheme of competitive pyrolytic changes :



As the size of *cyclo*alkane ring is increased ($C_5 \longrightarrow C_6 \longrightarrow C_7$) the yield of olefinic acid increases and that of lactone-lactam decreases, while the yield of hydroxy-anilide is not markedly affected. The three sets of figures quoted in Table 1 were obtained under strictly comparable conditions, and the trend is quite definite, though the yields should be regarded as minimum values because of slight manipulative losses.

TABLE 1.

Product (250°, 1 hr.)	Acid (I)	Acid (II)	Acid (III)
Aniline	17·5 (39)	23·2 (54)	26·0 (65)
Olefinic acid	3·9 (7)	21·5 (36)	31·1 (52)
Hydroxy-anilide	3·9 (4)	6·4 (6)	3·9 (4)
Lactone-lactam	15·0 (21)	10·1 (13)	8·0 (11)
Tars, water, losses	59·7	38·8	31·0

(Figures in parentheses represent % of theory based on conversion into a single constituent; the other figures represent % by wt. based on original acid.)

The yield of hydroxy-anilide from acid (II) varies with duration (*i.e.*, effective " contact-time ") and temperature of pyrolysis (13% at 160°, 48 hr.; 8% at 250°, ½ hr.).

Little gas is liberated during pyrolysis of acids (I—III) up to *ca.* 250°, though small amounts of carbon monoxide are evolved; but at *ca.* 500—550°, in a semimicro flow reaction vessel (see Experimental section), there is a large gaseous pyrolysate containing carbon monoxide and dioxide. It cannot be deduced from the gas analyses (Table 2)

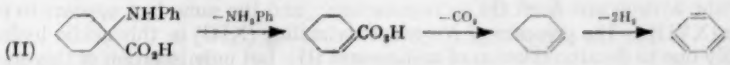
TABLE 2.

Gas produced (540°)	Anilino-acid (I)	Anilino-acid (II)	Olefinic-acid from (II)	Hydroxy-anilide from (II)	Lactone-lactam-from (II)
Yield of gas (%)	66 *	85 *	54 *	57 *	92 †
CO : CO_2 ratio (molar)	1·29	0·45	0·14	10·30	1·68

[Yields are calculated on assumption that one molecule of pyrolysand gives one (*) or two (†) molecules of gas.]

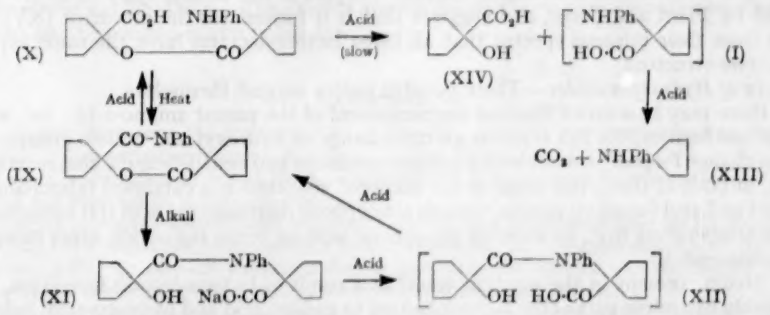
whether the gases produced from acids (I) and (II) arise in part directly from the acids themselves, or whether they are wholly due to secondary pyrolysis of the various primary breakdown products. It can, however, reasonably be concluded from the CO : CO_2 ratios that at 500—550° most of the carbon monoxide from acid (II) arises *via* the hydroxy-anilide (with the lactone-lactam as a subsidiary source), in sharp contrast to the fact that this hydroxy-anilide remains completely unchanged after 1 hr. at 250°.

In a vapour-phase flow vessel, at *ca.* 500° with a short contact time, the acid (II) gives a gaseous pyrolysate consisting of carbon monoxide (43%), carbon dioxide (40%), and hydrogen (17%), and a liquid pyrolysate containing aniline, *cyclo*hexene, and benzene. No hydroxy-anilide is obtained, though it may have been a transient precursor of at least part of the carbon monoxide. The constituents of the pyrolysate suggest that at high temperatures a major breakdown-route is the following :



A similar partial dehydrogenation of *cyclo*hexene to benzene has been observed in the pyrolysis of *cyclo*hexyl acetate at *ca.* 550° (Burns, Jones, and Ritchie, *J.*, 1935, 400).

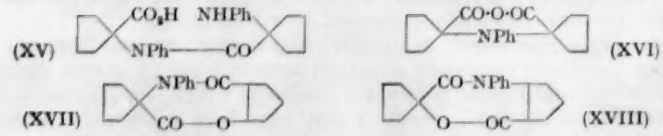
Since steam is formed during pyrolysis of acids (I—III), information is desirable on the mode of hydrolysis of the lactone-lactams. The hydrolysis of substance (IX) has therefore been studied in some detail, and occurs according to the following scheme :



It is very difficult to hydrolyse both the lactone (ester) and lactam (anilido) linkages of the lactone-lactam (IX), presumably because these bonds are formally due to the interaction of a carboxyl group, directly linked to a tertiary carbon atom, with a similarly attached hydroxyl or anilino-group respectively. Prolonged alkaline hydrolysis, followed by acidification of the solution, yields a sticky precipitate which slowly solidifies to regenerated lactone-lactam (95%) and probably consists of the unstable hydroxy-acid (XII) released from the salt (XI). Prolonged acidic hydrolysis leaves much of the original material unchanged; but some of the anilino-acid (X) is produced, which at 250° evolves water and regenerates the original substance (IX). Traces of 1-hydroxy*cyclo*pentanecarboxylic acid (XIV) and *N-cyclo*pentylaniline (XIII) are also formed, but none of the acid (I). Separate experiments showed that this anilino-acid is readily decarboxylated when heated with mineral acid.

Origin and Constitution of Lactone-lactams.—The structure (IX), proposed by Plant and Facer (*loc. cit.*) for the lactonic product from acid (I), lacks rigid experimental confirmation; and their simple equation (see above) representing the conversion of the acid (I) into the lactone-lactam (IX), aniline, and water is clearly a summation of two or more stages and does not indicate the immediate precursor of the lactone-lactam. If the first stage is formation of the anilino-acid (XV) by intermolecular elimination of water, it is not obvious why the second stage should be ring closure to lactone-lactam by elimination of aniline rather than to a dioxopiperazine by further elimination of water. On the other hand, since a major primary scission of acid (I) leads to aniline and an olefinic acid, it is

possible to formulate other plausible routes on the assumption that the first stage is addition of an amino-compound to an activated double bond, and the second a ring closure by loss of water, or *vice versa*. These routes should lead to one of the lactone-lactams (XVII) or (XVIII), in which there is a central seven-membered ring.



The anhydride structure (XVI) has been discussed and rejected by Plant and Facer. This rejection is confirmed by the presence of 1-hydroxy*cyclo*pentanecarboxylic acid (XIV) in the acidic hydrolysate from the lactone-lactam; and the same fact appears to rule out structure (XVII). The presence of *N-cyclo*pentylaniline (XIII) in this acidic hydrolysate is probably due to decarboxylation of anilino-acid (I); but only isolation of this acid could conclusively eliminate structure (XVIII), since the amine (XIII) might equally well arise by decarboxylation of the isomeric 2-anilino*cyclo*pentanecarboxylic acid. The fact, however, that an equimolecular mixture of the appropriate hydroxy-anilide and olefinic acid fails to interact at 250° argues against the formation of structure (XVIII) by addition *plus* dehydration of these two intermediates.

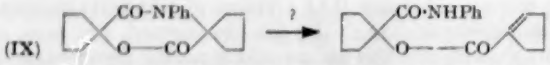
The new evidence now available therefore supports the double *spiro*-structure (IX) proposed by Plant and Facer, and suggests that it is formed *via* the precursor (XV). It is clear from their infrared spectra that all three lactone-lactams have the same type of double *spiro*-structure.

Origin of Hydroxy-anilides.—Three possible routes suggest themselves.

(i) There may be a direct thermal rearrangement of the parent anilino-acid; for, whatever the mechanism, the net result is an interchange of hydroxyl and anilino-groups. In this, the change formally resembles the pinacol–pinacone and benzil–benzilic acid rearrangements; in both of these, one stage in the accepted sequence is a catalysed interchange of hydroxyl and aryl (or alkyl) groups, though attempts to rearrange the acid (II) catalytically at room temperature (*e.g.*, by ethereal phosphoric acid, or boron trifluoride–ether complex) were unsuccessful.

(ii) Steam, present in the reaction vessel as a result of lactone-lactam formation, may conceivably hydrolyse part of the lactone-lactam to anilino-acid and hydroxy-acid, followed by reaction of the latter with free aniline to give hydroxy-anilide. However, complete hydrolysis of the lactone-lactam (IX) is extraordinarily difficult (see above); hydrolysis of one anilido-link followed by formation of another is a most unlikely sequence; and no hydroxy-anilide is formed (see Experimental section) when the lactone-lactam (IX) is heated with aniline and water (bath-temperature 260°).

(iii) There may be pyrolytic rupture of the lactone-lactam ring (IX), as shown below, followed by hydrolysis of the remaining ester linkage by the steam in the vessel, yielding hydroxy-anilide and olefinic acid :

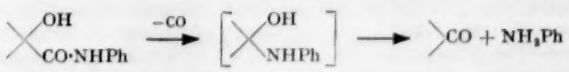


While there is nothing inherently improbable in this idea, it seems to be ruled out by the negative result of the test described in the previous section.

Of the three alternative routes, only direct thermal rearrangement of anilino-acid remains without contrary experimental evidence, though lacking direct proof; and this apparently novel reaction is being investigated further.

Since the hydroxy-anilide from acid (II) remains unchanged at 250°, this substance clearly cannot be the sole primary product from pyrolysis of the acid, leading to the other observed products by secondary reactions at the same temperature. It seems clear, therefore, that pyrolysis of the anilino-acids (I—III) must proceed by several concurrent competitive routes.

Origin of Carbon Monoxide.—Plausible schemes can be advanced, based on known analogous pyrolyses, to account for the formation of carbon monoxide from the substances mentioned in Table 2. For example, just as thermal decarboxylation of benzoic acid (*ca.* 370—400°) is accompanied by a minor scission to carbon monoxide and phenol (Moser, *Helv. Chim. Acta*, 1931, **14**, 971), *cyclo*hex-1-enecarboxylic acid might be expected to give a small amount of carbon monoxide and the enol of *cyclo*hexanone. Similarly, just as a lactide breaks down thermally very largely to carbon monoxide and an aldehyde or ketone (Blaise, *Compt. rend.*, 1904, **138**, 697; cf. Hurd, *op. cit.*, p. 426), the somewhat analogous lactone-lactams might be expected to yield carbon monoxide, a ketone, and the anil of the latter. Finally, the hydroxy-anilides might formally undergo primary conversion into aniline and a lactide, followed by pyrolysis of the latter as described above, or they might even lose carbon monoxide directly by the route :



All these tentative explanations suggest that the pyrolysate from acids (I—III) should contain the appropriate cyclic ketone or its anil; but there was no sign of either in two cases studied particularly [acid (I) at 250°; acid (II) at 500°; see Experimental section]. A control experiment showed that *cyclo*hexanone, intentionally added to the pyrolysand, is not completely destroyed under these conditions; and this argues against the correctness of the above explanations. The carbon monoxide in the various pyrolysates therefore remains for the present unaccounted for.

Experimental

Light petroleum was the fraction of b. p. 60—80°. Aniline was determined as described by Siggia, "Quantitative Organic Analysis," Wiley, New York, 1st Ed., 1949, p. 71. Solid products were identified by mixed m. p., supplemented in some cases by infrared spectra. Gas analyses are reported on a nitrogen-free basis.

Pyrolysis : *Macro-method* (*Static Reaction Vessel*).—The pyrolysand (50—80 g.) was heated under reflux in a small flask, immersed in a bath of Wood's metal. Temperatures were controlled to within ±5°. To prevent oxidation during pyrolysis, the system was thoroughly flushed with nitrogen before each run. The pyrolysate was fractionally distilled.

Pyrolysis : *Macro-method* (*Flow Reaction Vessel*).—In one run (see Table 3) at 500° (vapour phase) a flow reaction vessel of the type described by Allan, Forman, and Ritchie (*J.*, 1955, 2717) was used; here, also, the system was flushed with nitrogen before use.

Pyrolysis : *Semi-micro Method* (*Flow Reaction Vessel*).—The Pyrex-glass apparatus shown in Fig. 1 was used primarily for the collection and study of gaseous pyrolysates (see Table 2). The pyrolysand (300 mg.) was placed in bulb *A*; bulb *B* was then filled with glass beads (diam. *ca.* 3 mm.) up to a constriction at *C*, and the whole repeatedly evacuated and filled with nitrogen *via* inlets *D* and *E*. A short cylindrical electric furnace *F*, and the similar furnace *G* (in position 1), were raised to 540°; after 2 hr., *G* was moved to position 2, enclosing bulb *A*. The barometric leg *H* was adjusted during the run so as to collect the gaseous pyrolysate at approximately atmospheric pressure. Any non-gaseous pyrolysate was removed at the leg *J*, or the cold trap *K*. After pyrolysis (10 min.) the vessel was removed from the furnace and cooled (15 min.) : the total gas evolved was measured by the difference between the initial and final volume readings on the gas-burette. By lowering the mercury level of the collecting limb of the burette before closing the stopcock, *ca.* 80% of the gas in the system can be collected for analysis; Sleigh's method (*J. Soc. Chem. Ind.*, 1937, **56**, 430) was a particularly suitable analytical method. From the capacity of the reaction vessel (29 ml.) the total gas evolved can be calculated.

Preparation of 1-*Anilino*cyclo*alkanecarboxylic Acids* (I—III).—These were prepared from the corresponding anilino-nitriles (cf. Plant and his co-workers, *locc. cit.*) by hydrolysis of the nitrile to the amide by concentrated sulphuric acid, followed by hydrolysis of the amide to the acid by concentrated hydrochloric acid. Thus were obtained :

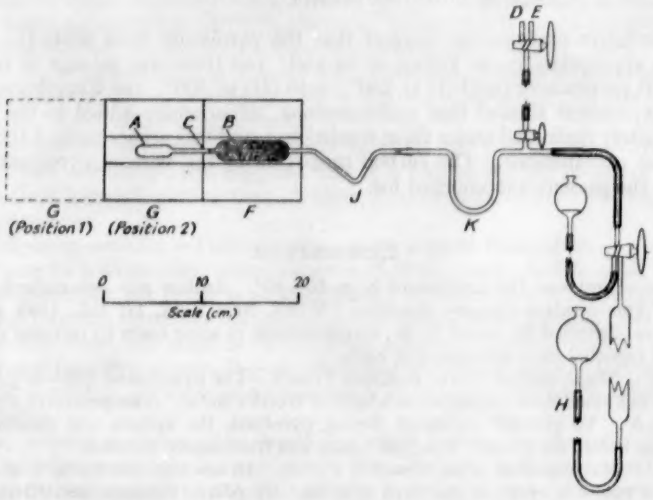
(*a*) 1-Anilino*cyclo*pentanecarboxylic acid (I) (63%), prisms (from xylene), m. p. 150—162° (decomp.) (Found : C, 70·4; H, 7·4; N, 6·8%; equiv., 205. Calc. for $C_{12}H_{15}O_2N$: C, 70·2;

H, 7·4; N, 6·8%; equiv., 205) [Plant and Facer, *loc. cit.*, give m. p. 162°. The acid gave the *N*-acetyl derivative, m. p. 183—194° (decomp.), in very poor yield (0·4%; 7 hr., acetic anhydride: 0·2%; 7 hr., acetyl chloride); Plant and Facer, *loc. cit.*, give m. p. 195° (yield not stated)].

(*b*) 1-Anilino*cyclo*hexanecarboxylic acid (II) (55%), fine needles (from benzene), m. p. 123—140° (decomp.) (Found: C, 71·4; H, 7·7; N, 6·3%; equiv., 218. Calc. for $C_{13}H_{17}O_2N$: C, 71·2; H, 7·8; N, 6·4%; equiv., 219) [Betts *et al.*, *loc. cit.*, give m. p. 142°; Bucherer and Barsch, *J. prakt. Chem.*, **1934**, **140**, 151, give m. p. 158°. A sample, kept at 160° for 30 min., lost 25% in wt., indicating marked decomposition just above the m. p.].

(*c*) 1-*Anilino*cyclo*heptanecarboxylic acid* (III) (78%), prisms (from benzene), m. p. 143—158° (decomp.) (Found: C, 72·0; H, 8·0; N, 6·3%; equiv., 234. $C_{14}H_{19}O_2N$ requires C, 72·1; H, 8·2; N, 6·0%; equiv., 233). The intermediate 1-*anilino*cyclo*heptanecarboxyamide* crystallised from ethanol as needles, m. p. 141—142° (Found: C, 72·2; H, 9·1; N, 12·0. $C_{14}H_{20}ON_2$ requires C, 72·4; H, 8·7; N, 12·1%).

Semimicro flow reaction vessel.



Although previous workers have reported a sharp m. p. for acids (I) and (II), it was observed that even after rigorous purification all three acids (I—III) melted indefinitely over a range of some 12° to 17°, indicating decomposition at the m. p.

Pyrolysis of 1-*Anilino*cyclo*alkanecarboxylic Acids* (*Macro-method*: *Static Reaction Vessel*).—(a) 1-*Anilino*cyclo*pentanecarboxylic acid* (I). Acid (50 g.), pyrolysed for 1 hr. at 250°, yielded (i) a fraction (9·9 g.), b. p. 150—210°, containing aniline (7·0 g.), *cyclo*pent-1-enecarboxylic acid (0·36 g.), and water, and (ii) a residue (39·4 g.). *cyclo*Pentanone and *cyclo*pentylideneaniline were absent from both (i) and (ii) (tested by 2 : 4-dinitrophenylhydrazine in dilute hydrochloric acid–ethanol). Residue (ii), extracted with aqueous sodium carbonate, yielded *cyclo*pent-1-enecarboxylic acid (1·76 g.), crystallising from light petroleum as prisms, m. p. 120—121° (Cook and Linstead, *J.*, 1934, 956, give m. p. 121°), and giving a dibromo-derivative, crystallising from acetic acid–water as prisms, m. p. 133—134° [Urion, *Ann. Chim.* (*France*), 1934, **1**, 5, gives m. p. 133°]. The alkali-insoluble residue from (ii), extracted with hydrochloric acid, yielded aniline (2·95 g.); the neutral residue gave 1-*hydroxy*cyclo*pentanecarboxyanilide* (1·55 g.), recrystallising from benzene as plates, m. p. 169—170° (Found: C, 69·9; H, 7·4; N, 7·1. $C_{12}H_{15}O_2N$ requires C, 70·2; H, 7·4; N, 6·8%). The identity of the anilide was confirmed by hydrolysis by concentrated hydrochloric acid to aniline hydrochloride and 1-hydroxy*cyclo*pentanecarboxylic acid, the latter recrystallising from benzene as plates, m. p. and mixed m. p. 103—104° (von Auwers and Krollpfeiffer, *Ber.*, 1915, **48**, 1389, give m. p. 103°), and by a mixed m. p. with synthetic anilide prepared by refluxing the hydroxy-acid with aniline. The liquors from the anilide, treated with light petroleum, yielded 12·4 g. of the crude lactone-lactam,

m. p. 130—144°; recrystallisation from benzene–light petroleum yielded 1-(1-hydroxy*cyclo*pentanecarboxyanilido)*cyclo*pentanecarboxylic lactone (IX) as prisms, m. p. 143—144° [Found: C, 72·4; H, 7·1; N, 4·7%; *M* (cryoscopic in benzene), 295. Calc. for $C_{18}H_{21}O_3N$: C, 72·2; H, 7·1; N, 4·7%; *M*, 299]. Plant and Facer (*loc. cit.*) give m. p. 142°. The equivalent weight, determined by back-titration of an alkaline hydrolysate, was 306.

(b) 1-*Anilino*cyclo*hexanecarboxylic acid* (II). This acid was pyrolysed, and the products isolated and identified, as for acid (I). The products were as follows (see Table 1 for yields): (i) *cyclo*Hex-1-enecarboxylic acid, b. p. 123—126°/7 mm., m. p. 29—31° [Found: equiv. (titration), 125. Calc. for $C_7H_{10}O_2$: equiv., 126], which gave a dibromo-derivative crystallising from benzene as plates, m. p. 144—145°. Betts *et al.* (*loc. cit.*) give m. p. 29—31° and 144° respectively. (ii) 1-Hydroxy*cyclo*hexanecarboxyanilide, crystallising from benzene as plates, m. p. 174—175° [Found: C, 71·3; H, 7·8; N, 6·5%; *M* (ebullioscopic in benzene), 214, 216. Calc. for $C_{13}H_{17}O_2N$: C, 71·2; H, 7·8; N, 6·4%; *M*, 219]. Bucherer and Barsch (*loc. cit.*) give m. p. 175°, and Passerini (*Gazzetta*, 1923, **53**, 410), m. p. 167°. Its identity was confirmed by hydrolysis (as above) to aniline hydrochloride and 1-hydroxy*cyclo*hexanecarboxylic acid, the latter crystallising from benzene as plates, m. p. and mixed m. p. 107—108° (Bucherer and Brandt, *J. prakt. Chem.*, 1934, **140**, 129, give m. p. 108°), and by comparison of the infrared spectra of synthetic and pyrolytic anilides. (iii) The lactone-lactam, 1-(1-*hydroxy*cyclo*hexanecarboxyanilido*)cyclo*hexanecarboxylic lactone*, crystallising from light petroleum as prisms, m. p. 157—158°, less readily soluble than compound (IX) in warm dilute alkali [Found: C, 73·7; H, 7·7; N, 4·5%; *M* (cryoscopic in benzene), 330, 331. $C_{20}H_{25}O_3N$ requires C, 73·4; H, 7·7; N, 4·3%; *M*, 327].

(c) 1-*Anilino*cyclo*heptanecarboxylic acid* (III). This acid was pyrolysed, and the products isolated and identified, as for acid (I). The products were as follows (see Table 1 for yields): (i) *cyclo*Hept-1-enecarboxylic acid, needles, m. p. 50—51°, from light petroleum [Found: C, 68·4; H, 8·9%; equiv. (titration), 140. Calc. for $C_8H_{12}O_2$: C, 68·5; H, 8·6%; equiv., 140]. Buchner and Jacobi (*Ber.*, 1898, **31**, 399) give m. p. 51—53°. (ii) 1-*Hydroxy*cyclo*heptanecarboxyanilide*, plates (from benzene), m. p. 171—172° (Found: C, 72·4; H, 8·1; N, 6·3. $C_{14}H_{19}O_2N$ requires C, 72·1; H, 8·2; N, 6·0%). Its identity was confirmed by hydrolysis (as above) to aniline hydrochloride and 1-hydroxy*cyclo*heptanecarboxylic acid, plates (from benzene), m. p. 78—79° (Buchner, *Ber.*, 1897, **30**, 1949, give m. p. 79—80°), and by mixed m. p. with synthetic anilide. (iii) The lactone-lactam 1-(1-*hydroxy*cyclo*heptanecarboxyanilido*)cyclo*heptanecarboxylic lactone*, prisms, m. p. 132—133° (from benzene–light petroleum), less readily soluble than compound (IX) in warm dilute alkali (Found: C, 74·2; H, 7·9; N, 4·3. $C_{22}H_{29}O_3N$ requires C, 74·3; H, 8·2; N, 3·9%).

Pyrolysis of 1-*Anilino*cyclo*hexanecarboxylic Acid* (II) *at* 500° (*Macro-method*: *Flow Reaction Vessel*).—The acid (89 g., 0·407 mole) was fed steadily in pellet form into the vessel during 3 hr. The gaseous pyrolysate (10·2 l. at N.T.P.) consisted of carbon monoxide (42·7, 44·0%), carbon dioxide (39·9, 39·9%), and hydrogen (17·4, 16·1%). The liquid pyrolysate (70·2 g.) yielded (i) (12·1 g.) b. p. 68—82°/760 mm., (ii) (0·9 g.) b. p. 45—86°/28 mm., (iii) (26·8 g.) b. p. 86—92°/28 mm., and (iv) a tarry residue. Fraction (i) was a mixture of *cyclo*hexene and benzene (*ca.* 2 : 1 molar), characterised by conversion into adipic acid and *m*-dinitrobenzene respectively and by infrared spectra. Fraction (iii) contained aniline (25·7 g.). Fractions (ii) and (iii) and residue (iv) contained no *cyclo*hexanone or *cyclo*hexylideneaniline (tested by 2 : 4-dinitrophenylhydrazine in dilute hydrochloric acid–ethanol); residue (iv), treated with benzene, gave no hydroxy-anilide. The yields were as in Table 3.

TABLE 3.

	CO	CO_2	H_2	C_6H_{10}	C_6H_6	NH_2Ph
Wt. (g.)	3·4	5·0	0·1	8·1	4·0	25·7
Mole	0·133	0·123	0·052	0·099	0·051	0·277
% of theory	33	30	6·4 *	24	12·5	68

* On assumption that 1 mole of acid (II) leads *via cyclo*hexene to 2 moles of hydrogen.

Prolonged Acidic Hydrolysis of 1-*Anilino*cyclo*pentanecarboxylic Acid* (I).—The acid (0·60 g.) was refluxed for 50 hr. with 4N-sulphuric acid (25 ml.); when made alkaline and extracted with ether, the hydrolysate yielded *N-cyclo*pentylaniline (XIII) (0·13 g.), identified as its acetate, m. p. and mixed m. p. 95—96°. Loevenich, Utsch, Moldrickx, and Schaefer, *Ber.*, 1929, **62**, 3094, give m. p. 96°.

Attempted Catalytic Rearrangement of 1-*Anilino*cyclo*hexanecarboxylic Acid* (II).—Concentrated phosphoric acid (6 ml.) was added to a solution of the anilino-acid (0·2 g.) in ether

(20 ml.); in a control experiment, the anilino-acid (0·18 g.) contained 1-hydroxy*cyclo*hexanecarboxyanilide (0·02 g.). After 15 days at room temperature, the former solution (homogeneous) yielded no hydroxy-anilide; the latter yielded 0·019 g. of the added hydroxy-anilide, m. p. and mixed m. p. 174—175°. Hence, there was no appreciable rearrangement of acid (II) in the first experiment.

Thermal Stability of 1-*Hydroxy*cyclo*hexanecarboxyanilide.*—The anilide, heated to 250° for 1 hr., remained unaltered in weight, m. p., and mixed m. p. (contrast pyrolysis at 540°: see Table 2).

Hydrolysis of Lactone-lactam (IX).—(a) ***With sodium hydroxide.*** The lactone-lactam dissolved readily in warm dilute sodium hydroxide; addition of dilute mineral acid then precipitated a sticky paste which gradually solidified. The solid product was regenerated lactone-lactam, m. p. and mixed m. p. 143—144° (95% recovery).

(b) *With sulphuric acid.* The lactone-lactam (2·8 g.) was refluxed (20 hr.) with 4N-sulphuric acid. Unchanged material (1·06 g.) was filtered off; the filtrate, brought to pH *ca.* 5 by dilute sodium hydroxide, afforded 1-*carboxy*cyclo*pentyl* 1-*anilino*cyclo*pentanecarboxylate* (X), recrystallising from benzene as diamond-shaped prisms, m. p. 148—155° (decomp.) [Found: C, 68·5; H, 7·1; N, 4·5%; equiv. (titration), 316. $C_{18}H_{23}O_4N$ requires C, 68·1; H, 7·3; N, 4·4%; equiv., 317]. A trace (*ca.* 2 mg.) of 1-hydroxy*cyclo*pentanecarboxylic acid (XIV) was also formed (m. p. and mixed m. p. 103—104°). Compound (X) was readily soluble in dilute sodium hydroxide, soluble with difficulty in dilute sulphuric acid [less soluble than acid (I)], gave a light yellow oil on treatment with nitrous acid, and when heated for 5 min. at 250° evolved water and regenerated the original lactam-lactone, m. p. and mixed m. p. 143—144° (identity confirmed by infrared spectrum). In a further hydrolysis of the lactone-lactam (5·47 g.), the acid hydrolysate was made alkaline; ether-extraction then yielded N-*cyclo*pentylaniline (XIII) (0·15 g.), identified as its acetate, m. p. and mixed m. p. 95—96°.

Attempted Ring-opening of Lactone-lactam (IX) *with Aniline and Water.*—The lactone-lactam (1·08 g.) was heated for 1 hr. under reflux (bath, 250°) with aniline (0·98 g.) and water (0·3 g.) (approx. molar ratio of reagents, 1 : 3 : 5). The residue was dissolved in benzene (15 ml.) and extracted with hydrochloric acid to remove aniline; no hydroxy-anilide was obtained.

Attempted Combination of cyclo*Hex*-1-*enecarboxylic Acid with* 1-*Hydroxy*cyclo*hexanecarboxyanilide.*—The acid (1·23 g.) was heated for 1 hr. under reflux (bath, 260°) with the anilide (2·14 g.). The only detectable products were unchanged acid (0·96 g.), m. p. and mixed m. p. 29—31°, and unchanged anilide (1·86 g.), m. p. and mixed m. p. 174—175°.

New Infrared Data.—The following are the principal infrared absorption bands of the compounds studied.

Anilino-acid (I): 1715(s), 1615(ms), 1514(m), 1335(m), 1297, 1276 (doublet; m), 1210(m), 1193(w), 962(m) cm.$^{-1}$.

Anilino-acid (II): 1635(s), 1508(w), 1388(s), 1316(w), 1274(w) cm.$^{-1}$.

Anilino-acid (III): 1715(m), 1615, 1576 (doublet; s), 1520(ms), 1355(m), 1340(ms), 1296(m), 1258(m), 1205(m) cm.$^{-1}$.

Hydroxy-anilide from (I): *ca.* 3430(s), 1669(s), 1622(s), 1570(s), 1349(m), 1185(m), 1048(m), 1018(m) cm.$^{-1}$.

Hydroxy-anilide from (II): *ca.* 3450(s), 1670(s), 1625(ms), 1570(s), 1175(ms), 1155(m), 1048(w), 996(ms) cm.$^{-1}$.

Hydroxy-anilide from (III): *ca.* 3490(ms), 1686(s), 1620(m), 1570(ms), 1465(s), 1070(m), 1050(w) cm.$^{-1}$.

Lactone-lactam from (I): 1760(s), 1680(s), 1512(m), 1405(s), 1342(s), 1282(s), 1244(ms), 1175(s), 1126(m), 1028(m) cm.$^{-1}$.

Lactone-lactam from (II): 1750(ms), 1685(ms), 1354(s), 1318(ms), 1271(m), 1231(s), 1131(ms), 1010(m) cm.$^{-1}$.

Lactone-lactam from (III): 1750(s), 1680(s), 1416(m), 1309(ms), 1261, 1242 (doublet; m), 1184(m), 1050(m) cm.$^{-1}$.

Anilino-acid (X): 1740(s), 1630(m), 1526(m), 1340(s), 1282(m), 1190(ms) cm.$^{-1}$.

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Studies in the Chemistry of Quadrivalent Germanium. Part III. Ion-exchange Studies of Solutions containing Germanium and Oxalate.*

By D. A. Everest.

[Reprint Order No. 6600.]

The results of anion-exchange studies on germanate solutions in presence of oxalates above pH 7 are interpreted in terms of the sorption of penta- and mono-germanate ions and of oxalate ions. These results confirm the conclusions reached in Parts I and II * concerning the pH dependence of the formation and degradation of the pentagermanate ion.

Although above pH 7 no complex ions could be detected, below pH 6 the ion-exchange data indicate that complex germanium–oxalate ions are being sorbed by the exchanger. Below *ca.* pH 3 the germanioxalate ion, $[Ge(C_2O_4)_3]^{2-}$, appears to be the chief species sorbed, whilst from pH 3 to 6, $[GeO(C_2O_4)_2]^{2-}$ and $[GeO_2(C_2O_4)]^{2-}$ ions are mainly taken up by the exchanger. Further evidence for the existence of the last two ions has been given by anion-exchange studies on germanate solutions containing insufficient oxalate to convert all the germanium into $[Ge(C_2O_4)_3]^{2-}$ ions.

The formation of a complex germanic oxalate was first observed by Bardet and Tchakarian (*Compt. rend.*, 1929, **189**, 914) on dissolving germanium dioxide in oxalic acid solution. Although they did not isolate free germanioxalic acid, measurements of the oxalic acid : germanium ratio in solution led them to assign the formula $H_2Ge(C_2O_4)_3$ to the complex. Germanium dioxide was also found to be highly soluble in solutions of ammonium hydrogen oxalate; evaporation of these solutions gave only thick uncrystallisable syrups from which no solids could be isolated. Determination of the oxalate : germanium ratio led Bardet and Tchakarian to suggest the presence in these syrups of the compound $Ge(C_2O_4)_2,GeO(C_2O_4),xH_2O$. Further evidence for the existence of germanioxalic acid, $H_2Ge(C_2O_4)_3$, has been obtained by Tchakarian [*Compt. rend.*, 1937, **204**, 356; *Ann. Chim.* (*France*), 1939, **12**, 415] and by Willard and Zuehlke (*Ind. Eng. Chem. Anal.*, 1944, **16**, 322) through their isolation of salts of this acid with quinine, strychnine, and 5 : 6-benzoquinoline. Tchakarian also showed that germanic oxalate complexes were sufficiently stable not to be decomposed by hydrogen sulphide, and he applied this fact in devising a method for the extraction of germanium from germanite.

If in germanioxalic acid the three oxalate groups are arranged octahedrally around the central germanium atom, it should be possible to resolve this complex into optically active forms. This was demonstrated by Moeller and Nielsen (*J. Amer. Chem. Soc.*, 1953, **75**, 5106) through the fractional crystallisation of the quinine salt described by Tchakarian (*loc. cit.*). In aqueous solution the free acid racemised, all activity being lost after 40 hr. These authors also obtained qualitative evidence for the occurrence of the $[Ge(C_2O_4)_3]^{2-}$ ion in the quinine salt by *X*-ray powder photographs.

Further evidence for the complex character of solutions of quadrivalent germanium in oxalate media has been furnished by Douvillé, Duval, and Lecompte (*Compt. rend.*, 1941, **212**, 697) and by Everest (*J.*, 1953, 4117). The former showed that the infrared spectra of such solutions had features characteristic of the spectra given by solutions of complex oxalates as a class. Everest showed that in presence of oxalates quadrivalent germanium was not reduced to the bivalent state by hypophosphorous acid, although this reduction occurred readily in less strongly complex-forming media.

In view of the utility of ion-exchange methods in elucidating the nature of simple germanate solutions (Everest and Salmon, Part I, *loc. cit.*) and in detecting the existence of the complex anions $[GeO_2(SO_4)]^{2-}$ and $[HGeO_2(PO_4)]^{2-}$ (*idem*, Part II, *loc. cit.*), it was considered that similar studies on solutions of germanium dioxide in oxalate media would throw new light on the formation, type, and stability limits of the germanic oxalate complexes.

* Parts I and II, *J.*, 1954, 2438; 1955, 1444.

Experimental

Solutions.—Stock solutions were prepared by dissolving pure germanium dioxide in boiled-out distilled water; these solutions contained 28—29 mmoles of germanium per l. The pH and the oxalate concentration of the solutions were varied by addition of oxalic acid, sodium oxalate, or sodium hydroxide. The solutions, containing a known amount of germanium (1·3—1·4 mmoles), were diluted to 75 ml. before addition of resin.

Anion-exchanger.—Analytical-grade Amberlite IRA-400 (supplied in the hydroxide form) was used throughout (in 0·25-g. samples) after conversion into the oxalate form, obtained by stirring the hydroxide form with excess of *ca.* 0·5N-oxalic acid, washing the resin by decantation, stirring it with successive portions of distilled water (time of contact 24 hr. with each portion), and finally air-drying it. Thus prepared, the resin lost a minimum of oxalate by hydrolysis during washing.

Equilibrium Experiments and Analytical Methods.—A period of 12—14 days was allowed for equilibrium between the solution and the resin phase to be established, at least 24 hours' mechanical shaking being included in this period. The separation of the solution and the resin phase, the estimation of the germanium sorbed by the resin, and the measurement of the pH of the solutions and of the capacities of the various resin samples were all carried out as in Part I (*loc. cit.*). The oxalate sorbed on the resin was eluted with 500 ml. of 3N-sulphuric acid during 48 hr. and then determined in the eluate by titration with standard potassium permanganate.

Results.—The quantities of germanium and of oxalate sorbed by the resin from solutions (75 ml.) of varying pH containing 1·2—1·4 mmoles of germanium and with 1·35, 2·85, and 5·35 mmoles of oxalate present are shown in Tables 1 (pH values above 7) and 2 (pH values below 7). A few values for germanium sorptions only, with 0·35 mmole of oxalate present, are also given in Table 1. At pH 4·5, or less, the amount of germanium sorbed reached a nearly constant value of 0·5—0·6, and that of the sorbed oxalate 1·4—1·6, moles per equiv. of resin (Table 2). Above pH 7 (Table 1) the germanium and oxalate sorptions followed the same course as did those of germanium and chloride (obtained in parallel experiments) reported in Parts I and II (*locc. cit.*); the amount of germanium sorbed reaching a maximum, and that of the oxalate a minimum, at pH 9·0—9·2. Between pH 6 and 7 the sorption of germanium by the exchanger fell nearly to zero, whilst that of the oxalate approached the value required for saturation of the resin with simple oxalate ions (Table 2). A maximum of *ca.* 50% of the germanium initially present in solution (with 1·35 and 2·85 mmoles of oxalate present) was sorbed by the resin at pH 9·0—9·2; with only 0·35 mmole of oxalate present this value was increased to *ca.* 80%. Below pH 4, with 2·85 and 5·35 mmoles of oxalate present, the maximum sorption was *ca.* 25%.

In control experiments it was found that, with 2·85 mmoles of oxalate in 75 ml. solution, the moles of oxalate sorbed per equiv. of resin (R_{ox}) varied from 0·54 at pH 4·9 to 0·82 at pH 1·9. Above pH 6 only $C_2O_4^{2-}$ ions were sorbed by the resin.

Discussion

Experiments at pH *Values above* 7.—The results obtained in this pH region (Table 1) confirm the conclusions reached in Parts I and II (*locc. cit.*) that the maximum in the germanium sorption at pH 9·0—9·2 is due to the uptake of pentagermanate ions by the resin, and that the decrease in the germanium sorption on either side of pH 9·0—9·2 results from the progressive degradation of pentagermanate ions into monogermanate. By the method of calculation described in Part II it has been possible to account quantitatively for the capacity of the resin samples used in terms of the sorption of mono- and penta-germanate ions and of oxalate ions. This is illustrated by the closeness of the values in the columns ($X + C_2O_4$) and ($X' + C_2O_4$) of Table 1 to the ideal value of one equiv. sorbed per equiv. of resin.

No evidence has been found for the sorption of any complex germanium–oxalate ions above pH 7. This is in contrast to the behaviour of solutions of germanates in presence of sulphate or phosphate (Part II), where, under conditions similar to those occurring in the present work, the complex anions $[GeO_2(SO_4)]^{2-}$ and $[HGeO_2(PO_4)]^{2-}$ were sorbed by the resin between pH 7 and 9·5. It is noteworthy that Willard and Toribara (*J. Amer. Chem. Soc.*, 1942, **64**, 1749) found that no combination occurred between quadrivalent tin and oxalate in alkaline media.

Experiments at pH *Values below* 7.—The increase in the germanium sorption from nearly

zero at pH 6 to *ca.* 0·5 mole per equiv. of resin below pH 4·5, together with the parallel increase in oxalate sorption, is direct evidence for the presence of sorbable germanium oxalate complexes in solution. By comparison, in the germanium–chloride system (Part I)

TABLE 1. *Sorption of germanium and of oxalate from solutions* (75 *ml.*) *at* pH *values above* 7 *by* IRA-400-C_2O_4 (0·25 *g.*).

pH of soln.	Germanium sorbed: • moles per equiv. of resin	X = Ge/R_{Ge} (equiv.)	X′ = Ge/2·5 (equiv.)	Oxalate sorbed, moles per equiv. of resin	Simple ions X + C_2O_4	Simple ions X′ + C_2O_4
	(*a*) 1·320 Mmoles of germanium, 2·85 mmoles of oxalate present.					
7·78	0·190	0·067	0·056	0·468	1·00	0·99
8·26	0·391	0·170	0·156$_5$	0·398	0·98	0·95
8·84	0·685	0·274	0·274	0·383	1·04	1·04
9·00	0·732	0·293	0·293	0·358	1·01	1·01
9·32	0·858	0·343	0·343	0·347	1·04	1·04
9·74	0·740	0·322	0·296	0·350	1·02	1·00
10·02	0·504	0·240	0·202	0·392	1·02	0·99
10·26	0·202	0·101	0·081	0·412$_5$	0·93	0·91
	(*b*) 1·320 Mmoles of germanium, 1·35 mmoles of oxalate present.					
7·40	0·151	0·075	0·056	0·475	1·03	1·01
7·80	0·347	0·158	0·139	0·441	1·04	1·02
8·46	0·575	0·243	0·228	0·378	1·00	0·98
9·06	0·803	0·321	0·321	0·367	1·05	1·05
9·42	0·828	0·345	0·331$_5$	0·348	1·04	1·03
9·62	0·730	0·319	0·293	0·398	1·19	1·09
	(*c*) 1·45 Mmoles germanium, 0·35 mmole of oxalate present.					
5·10	0·065	—	—	—	—	—
7·24	0·539	—	—	—	—	—
8·36	1·340	—	—	—	—	—
9·14	1·460	—	—	—	—	—
9·76	1·380	—	—	—	—	—
10·12	0·982	—	—	—	—	—

• X and X′ are defined in Part II (*loc. cit.*).

TABLE 2. *Sorption of germanium and of oxalate from solutions* (75 *ml.*) *at* pH *values below* 7 *by* IRA-400-C_2O_4 (0·25 *g.*).

pH of soln.	Species sorbed (moles per equiv. of resin) Ge	oxalate	Ratio moles oxalate : moles Ge on resin	Ions sorbed by resin
(*a*) 1·395 Mmoles of germanium, 5·35 mmoles of oxalate. Ratio oxalate : germanium in solution = 4·82.				
6·80	0·034	0·519	15·3	$C_2O_4^{2-}$, $[GeO_2(C_2O_4)]^{2-}$, and $[GeO(C_2O_4)_2]^{2-}$
5·56	0·230	0·598	2·6	
5·28	0·337	0·792$_5$	2·35	
4·84	0·471	0·951	2·02	
4·42	0·507	1·052	2·08	$[GeO(C_2O_4)_2]^{2-}$
3·96	0·493	1·065	2·16	
3·42	0·510	1·347	2·64	
3·00	0·510	1·434	2·81	
2·54	0·508	1·460	2·87	
2·04	0·536	1·511	2·82	Mainly $[Ge(C_2O_4)_3]^{2-}$
1·76	0·553	1·558	2·82	
1·58	0·543	1·564	2·88	
1·46	0·545	1·524	2·80	
(*b*) 1·320 Mmoles of germanium, 2·85 mmoles of oxalate. Ratio oxalate : germanium in solution = 2·04.				
6·60	0·060	0·510	8·5	
5·66	0·171	0·648	3·8	
5·18	0·282	0·735	2·61	$C_2O_4^{2-}$, $[GeO_2(C_2O_4)]^{2-}$, and $[GeO(C_2O_4)_2]^{2-}$
4·78	0·450	0·929	2·06	
4·40	0·564	0·955	1·69	
4·38	0·545	1·038	1·91	
3·36	0·629	1·263	2·01	
2·22	0·597	1·470	2·46	Mainly $[GeO(C_2O_4)_2]^{2-}$ with some $[Ge(C_2O_4)_3]^{2-}$
2·02	0·666	1·446	2·17	
1·86	0·603	1·481	2·45	

where no complexing occurs under conditions closely related to those in the present work, the sorption of germanium tended to zero below pH 6. The sorption of oxalate in presence of germanium (Table 2) is also greater, at any pH value below 6, than that required for saturation of the resin with simple oxalate ions.

In the experiments at the higher oxalate concentration (oxalate : germanium ratio in solution 4·82, Table 2) the resin, below pH 3, appears to be nearly saturated with a complex anion containing 3 moles of oxalate to one of germanium, as is illustrated by the value of *ca.* 2·85 for the ratio of oxalate to germanium in the resin phase (Table 2). This complex is probably the bivalent germanioxalate ion, $[Ge(C_2O_4)_3]^{2-}$, the existence of which has been indicated by the work of Bardet and Tchakarian, Tchakarian, Willard and Zuehlke, and Moeller and Nielsen (*locc. cit.*). The closeness of the amount of germanium sorbed to 0·5 mole per equiv. of resin is consistent with the sorption of a bivalent ion. A small amount of a univalent ion, such as $[HGe(C_2O_4)_3]^-$ or $[HGeO(C_2O_4)_2]^-$ (see below) may also be sorbed below pH 2 where the amount of germanium on the resin rises slightly over 0·5 mole per equiv. of resin.

From pH 3 to 4·5 the ratio of oxalate to germanium in the resin phase falls from 2·85 to 2 (Table 2). A bivalent ion is still taken up by the resin in this pH region, however, as the amount of germanium sorbed remains approximately constant at 0·5 mole per equiv. of resin. These two facts can be accounted for by assuming the sorption of increasing quantities of a complex ion such as $[Ge(OH)_2(C_2O_4)_2]^{2-}$ or $[GeO(C_2O_4)_2]^{2-}$. Sorption of small amounts of such an ion would account for the slightly low oxalate : germanium ratio (2·8—2·9) in the resin phase below pH 3 where $[Ge(C_2O_4)_3]^{2-}$ ions are considered to be the chief species sorbed.

The rapid decrease in the amounts of germanium and oxalate sorbed by the exchanger between pH 4·4—4·8 and 6·8, in both the higher and the lower oxalate concentration series (Table 2), indicates that decomposition of the germanium–oxalate complexes occurs in this pH range. This range is close to the pH value of 5·2 at which Willard and Toribara (*loc. cit.*), by means of pH titrations, found that solutions of quadrivalent tin in oxalate media decomposed to give hydrated stannic oxide. The increase in the ratio of oxalate to germanium in the resin phase observed between pH 4·4 and 6·8 (Table 2) is due, not to sorption of complexes with an increased oxalate : germanium ratio, but to the replacement of complex ions on the resin by oxalate ions. This is confirmed by the parallel decrease observed in the amount of germanium sorbed by the resin.

By using Jameson and Salmon's method of calculation (*J.*, 1954, 4013), attempts were made, between pH 4·8 and 6·8, to account for the capacity of the resin samples used in terms of the sorption of oxalate ions and either $[GeO(C_2O_4)_2]^{2-}$ or $[GeO_2(C_2O_4)]^{2-}$ ions alone. These attempts failed, the former possibility giving low results for the capacity, and the latter high ones. Probably it is a mixture of these two ions, together with free oxalate, which is actually sorbed by the resin in this pH range. This mixture would contain mainly $[GeO(C_2O_4)_2]^{2-}$ ions at pH 4·8 and $[GeO_2(C_2O_4)]^{2-}$ ions at pH 5·56.

In the experiments at the lower oxalate concentration (oxalate : germanium ratio in solution 2·04, Table 2) it is not possible for all the germanium in solution to be converted into $[Ge(C_2O_4)_3]^{2-}$ ions, and the conditions are those favourable to the existence of $[GeO(C_2O_4)_2]^{2-}$ ions. In fact, below pH 4·4 (Table 2), principally $[GeO(C_2O_4)_2]^{2-}$ ions appear to be taken up by the exchanger, although the increase in the ratio of oxalate to germanium in the resin phase below pH 3 indicates that some $[Ge(C_2O_4)_3]^{2-}$ ions are then also being sorbed. The increase in the amount of germanium sorbed over 0·5 mole per equiv. of resin is more marked in the lower oxalate concentration series than in the higher one. This is possibly caused by the weaker acidic character of $H_2[GeO(C_2O_4)_2]$ as compared with $H_2[Ge(C_2O_4)_3]$, which causes sorption of some univalent $[HGeO(C_2O_4)_2]^-$ ions as the pH of the solution decreases.

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Mechanisms of Reactions in the Sugar Series. Part I. The Acid-catalysed Hydrolysis of α- and β-Methyl and α- and β-Phenyl D-Glucopyranosides.

By C. A. BUNTON, (the late) T. A. LEWIS, D. R. LLEWELLYN, and C. A. VERNON.

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By isotopic tracer methods and the criterion of molecularity based on Hammett's acidity function, the acid-catalysed hydrolysis of four glucopyranosides has been shown to proceed by unimolecular decomposition of their conjugate acids and to involve fission of hexose–oxygen bonds only. It is considered that all except two mechanisms are excluded by the observed facts.

ARMSTRONG and GLOVER (*Proc. Roy. Soc.*, 1908, *B*, **80**, 312), in one of the first investigations of the acid-catalysed hydrolysis of glycosides, measured the rates of hydrolysis of methyl α- and β-D-glucopyranosides and, on the basis of the five-membered ring formulæ then accepted, discussed the mechanism, suggesting that ring opening was involved. In a more extensive investigation the rates and activation energies of hydrolysis of a number of glucopyranosides were measured, at a fixed acid concentration, by Moelwyn-Hughes (*Trans. Faraday Soc.*, 1928, **24**, 309; 1929, **25**, 81, 503). He suggested that the activation energy rather than the rate coefficient was the true measure of reactivity, and he calculated the " number of degrees of freedom involved in the reactions " from activation energy data and the equation developed by Hinshelwood for unimolecular gas reactions. Heidt and Purves (*J. Amer. Chem. Soc.*, 1944, **66**, 1385) found that, irrespective of changes of structure within a group, the ease of hydrolysis at a particular acid concentration and at a particular temperature increased in the order glucopyranoside, fructopyranoside, fructofuranoside. More recently, Nath and Rydon (*Biochem. J.*, 1954, **57**, 1) measured the rates of hydrolysis, at a fixed acid concentration, of a number of substituted phenyl β-D-glucopyranosides and, certain exceptions apart, found that electron-withdrawing or electron-releasing substituents in the benzene ring produced, respectively, small increases and decreases in the rates of hydrolysis. These investigations concern the effect of structural changes on the rate or activation energy of hydrolysis, and it appears impossible to draw from them useful conclusions about the mechanisms of the reactions. This is not surprising since in acid-catalysed hydrolytic reactions the initial proton transfer is rarely rate-determining, so that a structural charge in the substrate may affect the overall rate and activation energy of the reaction in two ways: first, by changing the equilibrium concentration of the conjugate acid of the substrate; and, secondly, by changing its rate of breakdown. These two effects may operate in opposite directions, and predictions about them are especially difficult in the present case, partly because of the complexity of the substances involved and partly because of the multiplicity of possible reaction paths.

In this investigation we set out to determine (*a*) the positions of bond fission and (*b*) the molecularities of the rate-determining steps in four D-glucopyranosides which, on general grounds, might be expected to undergo hydrolysis by a common mechanism. As is shown later, the evidence obtained excludes all but two of the possible mechanisms for the hydrolysis of the four compounds studied.

RESULTS

The positions of bond fission were found by carrying out the reactions in water enriched in the isotope ^{18}O and measuring the excess abundance of ^{18}O in the methyl alcohol or phenol produced. The glucose produced in each reaction was isolated as the osazone and this was also isotopically analysed. The results, some of which have already been reported in a preliminary publication (Bunton, Lewis, Llewellyn, Tristram, and Vernon, *Nature*, 1954, **174**, 560), are given in Table 1. It is seen from these results that the hydrolysis of the compounds studied involves fission of the hexose–oxygen bonds, *e.g.*, $R\dot{}—O—Me + H_2{}^{18}O \longrightarrow R—{}^{18}O—H + H—O—Me$. It may also be concluded, from the results obtained with the glucosazones, that hydrolysis does not involve rupture of carbon–oxygen bonds at the 3-, 4-, 5-, or 6-position in the pyranoside ring.

TABLE 1.

D-Gluco-pyranoside	Acid	Temp.	% Excess abundance of ^{18}O: In solution	In MeOH or PhOH	In glucosazone *
Me α-	1·10N-HCl	80°	$0{\cdot}54_6$	$0{\cdot}00_5$	—
	1·81N-$HClO_4$	72·9	$0{\cdot}83_2$	$0{\cdot}01_2$	$0{\cdot}00_6$
Me β-	1·10N-HCl	80	$0{\cdot}54_0$	$0{\cdot}00_6$	—
Ph α-	2·19N-$HClO_4$	72·9	$0{\cdot}80_4$	$0{\cdot}00_3$	$0{\cdot}00_3$
Ph β-	2·19N-$HClO_4$	72·9	$0{\cdot}79_3$	$0{\cdot}00_3$	$0{\cdot}00_6$

* Referred to a normal sample of glucosazone.

The molecularities of the reactions were determined by use of the criterion based on Hammett's acidity function, H_0 (Hammett, "Physical Organic Chemistry," McGraw-Hill Book Co., Inc., New York, 1940, p. 273; Long and co-workers, see particularly McIntyre and Long, *J. Amer. Chem. Soc.*, 1954, **76**, 3240). This criterion distinguishes between the possibilities (*a*) and (*b*) in the scheme below, in which G and G^+H represent the glycoside and its conjugate acid respectively and G_1^+ represents some other entity formed from G^+H :

$$G + H_3O^+ \rightleftharpoons GH^+ + H_2O \quad \text{fast}$$

$$(a)\ \begin{cases} GH^+ \longrightarrow G_1^+ & \text{slow} \\ G_1^+ + H_2O \longrightarrow \text{Products} & \text{fast} \end{cases}$$

$$(b)\ GH^+ + H_2O \longrightarrow \text{Products} \quad \text{slow}$$

In (*a*) the rate-determining step is unimolecular and does not involve a water molecule and it can be shown that an approximate proportionality between the logarithm of the first-order rate coefficient (log *k*) and H_0 should be observed. In (*b*) the rate-determining step is bimolecular and it may similarly be shown that an approximate proportionality between log *k* and pH (defined as $-\log c_{H_3O^+}$) should result. In Table 2 are shown the rates of hydrolysis of the four

TABLE 2. *Hydrolysis of glucopyranosides in aqueous perchloric acid.*

D-Gluco-pyranoside	Temp.	$[HClO_4]$ (N)	H_0	10^3k_1 (min.$^{-1}$)	D-Gluco-pyranoside	Temp.	$[HClO_4]$ (N)	H_0	10^3k_1 (min.$^{-1}$)
Me α-	72·9°	0·465	+0·32	0·227	Ph β-	72·9	0·573	+0·21	4·78
		0·936	−0·07	0·552			0·848	+0·02	7·88
		1·552	−0·46	1·25			1·156	−0·20	12·0
		2·209	−0·79	2·42			1·715	−0·55	24·7
		2·722	−1·01	3·95			2·175	−0·78	38·0
		3·720	−1·38	9·09			2·880	−1·08	72·9
		2·272 *	−0·23	0·725					
		3·262 *	−0·52	1·28	Ph α-	72·9	0·549	+0·22	13·9
						57·4	0·551	+0·22	1·76
Me β-	72·9	0·485	+0·31	0·493			1·046	−0·13	4·32
		0·934	−0·04	1·12			2·127	−0·75	15·8
		1·566	−0·46	2·56			2·680	−0·99	21·7
		2·102	−0·74	4·22					
		2·688	−0·99	7·71					

D-Glucopyranoside	Me α-	Me β-	Ph β-	Ph α-
Slope of log *k* against H_0	−0·95	−0·91	−0·91	−0·89

* Sulphuric acid was used in these experiments.

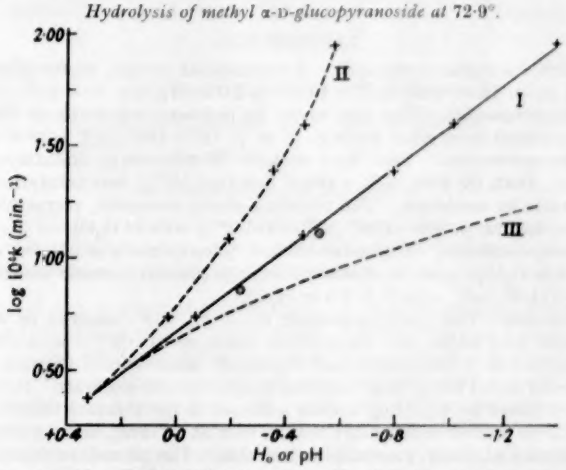
glucopyranosides in a range of acidities in which the numerical values of H_0 and pH differ sufficiently for diagnostic purposes. The Figure shows the rates for methyl α-D-glucopyranoside plotted against H_0 and against pH. It is clear that in all four cases log *k* and H_0 are nearly linearly related. The departures of the slopes from unity are small and have not been explicitly considered, particularly since the values of H_0 used are those measured at 25°, whereas the kinetic results have been obtained at higher temperatures. An analysis of factors leading to small departures from strict proportionality has been given by Long and McIntyre (*J. Amer. Chem. Soc.*, **1954, 76, 3243**).

DISCUSSION

The results show that, in the hydrolysis of the four compounds studied, the initial proton transfers are fast and reversible, and that the conjugate acids so formed then undergo slow unimolecular reactions. This is the only hypothesis consistent with the observed dependence of rate on acidity. McIntyre and Long (*loc. cit.*) have drawn similar

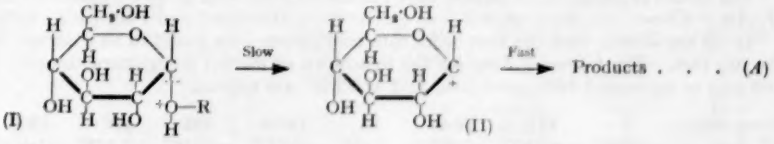
conclusions about the acid-catalysed hydrolysis of methylal; the similarity of the reaction mechanisms of this compound to that of the pyranosides, which have a similar general structure, is not surprising especially since, in the pyranosides, bimolecular attack on $C_{(1)}$ is unlikely for steric reasons. The rate-determining, unimolecular steps may be formulated in two ways: first, as in scheme (*A*) in which the conjugate acid (I) undergoes heterolysis to form the carbonium ion (II), subsequent reaction with water being rapid; or, secondly, as in scheme (*B*) in which the conjugate acid (III) undergoes ring-opening between the oxygen atom and $C_{(1)}$ to form the ion (IV), subsequent rapid stages involving attack by a molecule and loss of methanol or phenol. It is also formally possible that the slow steps involve isomerisation to the corresponding furanosides. As it seems reasonable, however, to suppose that isomerisation would take place by way of ring-opening, as in scheme (*B*), no alternative reaction mechanism is provided by such considerations.

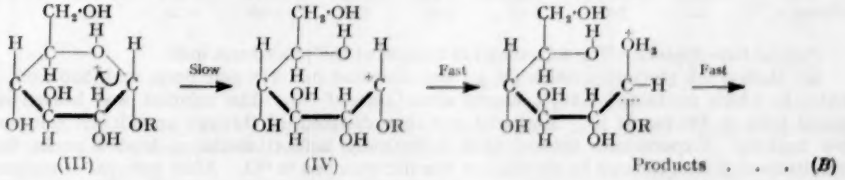
Hydrolysis of methyl α-D-*glucopyranoside at* 72·9°.



I, log *k plotted against* H_0. II, log *k plotted against* pH. III, *Hypothetical curve of* log *k plotted against* $[H_0]$ *for linear relation of* log *k and* pH.
+ *Perchloric acid.* ○ *Sulphuric acid.*

Both reaction schemes are consistent with the evidence at present available, and it does not seem easy to devise a distinguishing experimental test. In principle a stereo-





chemical test might be employed since scheme (*B*) probably involves the production, under kinetic control, of the equilibrium mixture of α- and β-glucose, whereas this is probably not the case for scheme (*A*). In acidic aqueous solutions, where the mutarotation

of D-glucose is very rapid, such considerations have no diagnostic value; however, for other solvents, such as methanol, a possible distinction based on stereochemical considerations is being investigated. Foster and Overend (*Chem. and Ind.*, 1955, 566) discussed structural and conformational effects in the hydrolysis of glycosides only in terms of scheme (*A*); we think that no decision between the two possibilities can yet be made.

It is not our view that all glucopyranosides undergo hydrolysis by mechanisms exactly specified by one or other of the above alternatives. It is possible, for example, that a group which is very much more electron-releasing than methyl might cause alkyl–oxygen rather than hexose–oxygen fission; the reaction would, however, still be unimolecular. It is interesting in this connection that the hydrolysis of sucrose, one of the first reactions to be investigated by the criterion based on Hammett's acidity function, was shown to proceed by a unimolecular mechanism (Hammett and Paul, *J. Amer. Chem. Soc.*, 1934, **56**, 830). The position of bond fission in this reaction is, however, unknown.

Experimental

Materials.—*Methyl α-D-glucopyranoside.* A commercial sample, recrystallised several times from ethanol, had m. p. 164—165°, $[\alpha]_D^{25}$ +157·8° (*c* 3·0 in H_2O).

Methyl β-D-glucopyranoside. This was made by conventional methods from acetobromoglucose and recrystallised from ethyl acetate, to m. p. 107—108°, $[\alpha]_D^{25}$ −32·6° (*c* 2·7 in H_2O).

Phenyl α-D-glucopyranoside. The tetra-acetate (Montgomery, Richtmyer, and Hudson, *J. Amer. Chem. Soc.*, 1942, **64**, 690), $[\alpha]_D^{25}$ +168·8° (*c* 0·8 in $CHCl_3$), was catalytically deacetylated by sodium methoxide in methanol. The resulting glucopyranoside, recrystallised from water and dried *in vacuo*, had m. p. 169—170°, $[\alpha]_D^{25}$ +181·1° (*c* 0·65 in H_2O).

Phenyl β-D-glucopyranoside. The tetra-acetate (Montgomery *et al.*, *loc. cit.*), m. p. 127°, $[\alpha]_D^{25}$ −30·7° (*c* 2·0 in C_6H_6), gave on deacetylation the glucopyranoside which, dried *in vacuo*, had m. p. 173·5—174·5°, $[\alpha]_D^{25}$ −70·7° (*c* 2·0 in H_2O).

Kinetic Experiments.—The glucopyranoside (1—3 g.) was dissolved in water, a suitable amount of perchloric acid added, and the solution made up to 100 c.c. with water. The whole was suitably immersed in a thermostat and vigorously shaken until thermal equilibrium was reached. Volumes of about 10 c.c. were removed at appropriate intervals. In early experiments the reaction was stopped by pipetting known volumes of the mixture into known volumes of excess of alkali. This proved unnecessary for the runs at 73° and, because of decomposition of glucose in the presence of alkali, generally undesirable. The procedure finally adopted was to pipette a sample of the reaction mixture directly into a jacketed polarimeter tube maintained at 25°. The errors introduced into the time readings by this procedure were small since cooling was rapid and the reactions have high activation energies (Moelwyn-Hughes, *loc. cit.*). When thermal equilibrium was established, the optical rotatory power of the solution was determined. In a number of runs the calculated value of the "infinity" reading was compared with the observed "infinity" reading. The differences were in general less than 2%.

The values of the acidity function were calculated from data given by Hammett and Deyrup (*J. Amer. Chem. Soc.*, 1932, **54**, 2721) as corrected by Hammett and Paul (*ibid.*, 1934, **56**, 827).

In all the kinetic runs the first-order rate coefficients were found to be constant throughout the reaction. The following data for the hydrolysis of methyl β-D-glucopyranoside (3·0107 g./100 c.c.) in aqueous 1·566N-perchloric acid at 72·95° are typical.

Time (min.)	0	22·5	50·5	85	137·2	193	276	1300	∞
α_D^{25}	−0·925°	−0·791°	−0·623°	−0·455°	−0·227°	−0·010°	+0·267°	+1·364°	+1·470°
10^3k (min.$^{-1}$)	—	2·57	2·67	2·57	2·51	2·56	2·50	2·40	—

Isotope Experiments.—The following are typical of the procedures used.

(*a*) Methyl α-D-glucopyranoside (20 g.) was dissolved in 1·81N-perchloric acid (250 c.c.), the water in which contained 0·83$_2$% excess abundance of ^{18}O. The solution was heated in a sealed tube at 73° for 24 hr. Methanol was then distilled off through an efficient column of low hold-up. Experiments showed that isotopically normal methanol heated under these conditions and then isolated by distillation was not enriched in ^{18}O. After removal of methanol the residue was neutralised. Sodium acetate and phenylhydrazine hydrochloride were then added, and the whole was heated until the formation of glucosazone was complete. The glucosazone was recrystallised from aqueous ethanol.

(*b*) Phenyl β-D-glucopyranoside (6 g.) was dissolved in 2·19N-perchloric acid (100 c.c.),

the water in which contained 0·79$_3$% excess abundance of ^{18}O. The solution was heated for 24 hr. at 73°, and then extracted with ether. The ether extract was dried and the ether then distilled off. The phenol so obtained was purified by distillation.

The abundance of ^{18}O in the solvent water was determined by equilibration with carbon dioxide, and that in the organic products by pyrolysis to carbon monoxide *in vacuo* in a graphite tube heated in an R.F. induction furnace. Mass-spectrometric analyses were made on carbon monoxide for both methanol and phenol. The nitrogen evolved in the pyrolysis of glucosazone interferes with mass-spectrometric measurements on carbon monoxide. Therefore, the carbon monoxide from the glucosazones was converted into carbon dioxide on heated nickel catalyst, and the mass-spectrometric analyses were made on this gas.

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Isotopic Studies on the Formation of Ketones by the Catalytic Decomposition of Certain Acids.

By ROWLAND I. REED.

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Studies on ketones formed by passing the vapour of an isotopically enriched acid over suitable catalysts suggest that, in accordance with the general evidence, the reaction is essentially the breakdown of the salt initially formed.

EARLIER studies of the pyrogenetic formation of aldehydes and ketones by isotopic tracer techniques (Bell and Reed, *J.*, 1952, 1383; Lee and Spinks, *Canad. J. Chem.*, 1953, **31**, 103; *J. Org. Chem.*, 1953, **18**, 1079) have now been extended to the "catalytic" formation of ketones. This method, passage of acid vapours over a suitable catalyst, was introduced by Squibb (*J. Amer. Chem. Soc.*, 1895, **17**, 187) as an alternative method for preparing acetone. Subsequently, mixtures of acids were used to prepare unsymmetrical ketones, and catalysts other than barium and calcium carbonates (Sabatier–Reid, "Catalysis in Organic Chemistry," D. Van Nostrand Co., New York, 1922, p. 839) were employed.

Experiments with [*carboxy*-^{13}C]propionic acid, passed with other acids over various catalysts, have given the results shown in Table 1. Mixtures of barium phenylacetate and labelled propionate in various proportions have also been studied (see Table 2). The

TABLE 1.

Expt. no.	Temp.	$\frac{R{\cdot}CO_2H}{Et{\cdot}CO_2H}$ [a] (mol. ratio)	R	Catalyst	Concn. (%) of ^{13}C in carbonyl-C: $Et{\cdot}CO_2H$	$R{\cdot}COEt$	R_2CO	% of CO group from $Et{\cdot}CO_2H$
1	430·5°	1	CH_2Ph	ThO_2	19·78	11·97	—	58·7
2	,,	1	,,	MnO	16·78	9·22	—	54·9
3	,,	1	,,	,,	,,	9·48	—	56·5
4	,,	5	,,	,,	19·78	12·62	2·38	62·4
5	,,	1	,,	$CaCO_3$	16·78	10·31	—	61·4
6	,,	5	,,	,,	19·78	12·83	3·34	63·4
7	,,	5	Ph [b]	,,	,,	1·98	1·14	3·8
8	,,	10	H [b]	,,	,,	2·08	—	5·5
9	,,	1	CH_2Ph	$BaCO_3$	16·78	9·39	—	56·0
10	,,	5	,,	,,	,,	10·63	2·61	63·4
11	520°	,,	,,	,,	19·78	4·66	—	19·6
12	,,	,,	,,	,,	,,	4·82	—	20·6

[a] This ratio is controlled by the partial vapour pressure of each component. [b] Comparable values for salt pyrolyses were obtained by Lee and Spinks (*loc. cit.*).

results show that the proportion of the carbonyl group in the benzyl ethyl ketone, derived from the propionate, is approximately constant at 60—65·8% whatever the relative proportions of the salts in the mixture. There is, moreover, no trend in the results with such a variation in the mixture.

TABLE 2. (*Temperature* 435–450°)

Expt. no.	Phenylacetate Propionate (mol. ratio)	Concn. (%) of ^{13}C in carbonyl-C: Pyrolysis mixture	$BaCO_3$ residue	$CH_2Ph{\cdot}COEt$	$(CH_2Ph)_2CO$	Et_2CO	Yield (%) of $CH_2Ph{\cdot}COEt$	% of CO group from propionate
1	0·50	22·14	20·02	40·94	—	58·5	11·0	63·8
2	1·00	32·64	31·60	38·53	2·70	—	5·7	60
3	,,	,,	31·20	41·40	—	61·8	6·9	64·5
4	2·00	43·15	37·49	40·65	2·56	—	21·0	63·3
5	5·00	11·63	10·03	39·47	1·85	—	23·3	61·5

The results for the salt pyrolyses and those of the catalytic method are similar. The enrichment of the carbonyl-carbon from the preparations of propiophenone and propionaldehyde by the latter method is the same as those reported for salt pyrolyses (Lee and Spinks, *loc. cit.*). The percentage of the ketonic carbon derived from the propionyl group in the formation of benzyl ethyl ketone is constant within experimental error, whichever catalyst or method is employed.

Eadie (personal communication) has shown that the percentage of the carbonyl-carbon derived from the acid ion is likewise independent of the metal ion present in pyrolyses of the salts.

These observations, together with the previously established fact that an effective catalyst is one that is capable of forming a salt with the acid (Conroy, *Rev. gen. Sci.*, 1902, **13**, 563; Ipatieff, *J. Russ. Phys. Chem. Soc.*, 1908, **40**, 514; *Abs.*, 1908, **94**, i, 386), support the view that salt formation is a preliminary step in the reaction. This is supported by the general observation that both modes of reaction occur within a similar temperature range (410—450°). Böeseken (*Rec. Trav. chim.*, 1920, **39**, 621) has reported increased yields of ketones by using the alkaline-earth oxides or carbonates as catalysts instead of the alkali-metal derivatives and this agrees with Krönig's conclusions (*Z. angew. Chem.*, 1924, **37**, 667) for salt decompositions. Bamberger's theory (*Ber.*, 1910, **43**, 3517), that reaction proceeds by alternate formation and decomposition of the anhydride, does not seem well adapted to explain ketone formation, at least in the simple systems here examined; such theories are not further considered here. Two theories have been proposed for the decomposition of salts (Bell and Reed, *loc. cit.*; Lee and Spinks, *loc. cit.*). The latter is principally concerned with ketone formation, for which an ionic mechanism is proposed. Evidence for this view is, in the present study, difficult to obtain. The decomposition of propionic acid over calcium carbonate at 440° yields small quantities of carbon monoxide, ethane, ethylene, and butane in addition to the main products, *viz.*, diethyl ketone, carbon dioxide, and water vapour. These by-products, with the exception of the last which suggests decomposition of the ketone, may be expected from the breakdown of either the acid or the ketone.

Preliminary results in a kinetic study of the formation of ketones by the pyrolysis of the salts of both mono- and di-carboxylic acids indicate mild catalysis by added carbon. A three-fold increase in velocity is the maximum that has been obtained with the catalyst and, with this present, the reactions are of an integral order with respect to the salt (Miss Thornley, personal communication). This supports an ionic mechanism, rather than a free-radical process, and is consistent with the high yield of ketone at 420—460° and with the lack of significant quantities of by-products such as might have been expected with a free-radical mechanism. In particular, no evidence has been obtained for the formation of an oxalate, which might be expected with a reaction mechanism of this type, analogous to that proposed for aldehyde formation (Bell and Reed, *loc. cit.*). Dimerisation of the postulated free radical $\cdot CO_2M$ would yield oxalate, the more so since in ketone formation there is no strong reducing agent present to destroy it, as might be the case with the formate present in aldehyde formation.

The essential mechanism of the reaction may be written:

$$R{\cdot}CO_2M + R'{\cdot}CO_2M \longrightarrow RR'CO + M_2CO_3$$

(where M = ½Ba, ½Ca, ½Mn, ¼Th; R, R′ = H, Et, Ph, CH_2Ph)

in which one molecule provides an acyl and the other an alkyl or an aryl group. In this study it was also possible that one of the reacting molecules would be in the form of a salt,

the other as an acid : this is improbable in view of the similarities already listed. There is moreover no evidence of the increased facility of reaction reported for pyrolyses of dicarboxylic acids and their salts (Kenner and Morton, *Ber.*, 1939, **72**, 452; Neunhoeffer and Paschke, *ibid.*, p. 919); and, with barium oxide as the catalyst, benzoic acid yields only the barium salt (Sabatier and Mailhe, *Compt. rend.*, 1914, **159**, 217) at 450—500°, there being no evidence of any facilitating of the reaction which occurs very slowly with this salt at 450°.

For formation of acetone from acetic acid vapour in the presence of barium or calcium carbonate, Rubinshtein and Pribythkova (*Doklady Akad. Nauk S.S.S.R.*, 1951, **78**, 917; *Chem. Abs.*, 1952, **46**, 33) adduced evidence for the intermediate formation of the appropriate salt.

Experimental

Barium [*carboxy*-^{13}C]propionate was prepared by the method used for the acetate (Bell and Reed, *J.*, 1952, 1383) with an overall yield of 86%. The salt was mixed with an equimolecular quantity of propionic acid which was subsequently removed by distillation, providing enriched samples of both the acid and the salt.

The pyrolyses were carried out in a tube loosely filled throughout its length (7″) with the catalyst. The temperature of the furnace, measured by a thermocouple in the tube, was controlled manually. The two acids were separately introduced into the tube, from small reservoirs, and allowed to mix immediately on entry. In some cases dry nitrogen was used as carrier, and in others the experiment was carried out at about 11 mm. pressure. No attempt was made to control exactly the relative amounts of each acid used; an approximate ratio was obtained by adjusting the temperature of the separate reservoirs which controlled the vapour pressure of each species. The condensable products were trapped in liquid air immediately on leaving the reaction vessel and, except in certain experiments, subsequently allowed to warm to room temperature, with the escape of the volatile material. The remaining liquid which frequently contained water was transferred to a small tube, then dried by mixing it with dry benzene and distilling this away. The residue was heated on a water-bath at 11 mm., whereupon a liquid distilled and condensed on the upper parts of the tube. This was converted into the semicarbazone which on recrystallisation yielded a pure sample of this derivative of benzyl ethyl ketone (m. p. 142—143°). In two favourable cases a preliminary distillation was carried out at normal pressures and a sample of diethyl ketone was obtained, which was converted into the semicarbazone which, on recrystallisation, had m. p. 137—138°. The residue from the reduced-pressure distillations, in nearly every case, solidified, and on recrystallisation gave pure dibenzyl ketone, m. p. 32°.

All the products were oxidised by Van Slyke and Folch's method (*J. Biol. Chem.*, 1940, **136**, 509) to carbon dioxide, which was analysed mass-spectrometrically in a Metropolitan-Vickers Ltd. Type M.S. 2 instrument.

In particular cases, by-products were analysed. Samples of propionic acid were passed over heated barium carbonate, and the issuing gases passed through a spiral trap immersed in liquid air and then into the mass-spectrometer. Under these conditions only carbon monoxide was detected. The pyrolyses were stopped, the contents of the trap warmed to the temperature of an acetone–solid carbon dioxide bath, and the liberated gases examined. Ethane was identified by the appearance of the characteristic mass spectrum (masses 26—30) together with some evidence for ethylene (26—28). On further warming of the trap in ice–salt (~ −10°), butane was also detected (masses 27, 28, 29, 41, 43). In general the quantity of by-products was small, particularly when the pyrolysis was slow. Significant concentrations occurred in the range 480—520°, and at 520° extensive decomposition of the ketone occurred.

Similar isotopic experiments were made at 500—540° to examine the possibility that a definite free-radical process might be demonstrated. The yield of ketone was however very small, that of the by-products large. Examination of the ^{13}C content of the carbonyl group showed about 20% to have been derived from the propionic acid. However, in view of the multiplicity of other products, and the absence of a knowledge of the kinetic factors involved in the reaction, these results are of doubtful significance.

Materials.—Formic acid (98—100%; from B.D.H.) was dried ($MgSO_4$) and distilled, large head and tail fractions being rejected. Propionic acid was treated similarly, the sample collected having b. p. 139—140°/764 mm. B.D.H. samples of benzoic and phenylacetic acids were recrystallised from aqueous ethanol, acids having m. p.s 120° and 76° respectively being retained.

Barium carbonate ("AnalaR") and calcium carbonate (powdered Iceland spar) were used as obtained. Manganous oxide was prepared from the carbonate by Vogel's method ("Practical Organic Chemistry," Longmans, Green and Co., London, 1948, p. 337). Thorium oxide was prepared by heating a Hopkin and Williams sample of the hydroxide at 1100° for 3 hr.

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Organic Oxidation Processes. Part IV. The Reaction of Lead Tetra-acetate with Some Carbonyl Compounds.*

By G. W. K. CAVILL and D. H. SOLOMON.

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Lead tetra-acetate readily effects the α-acetoxylation of simple ketones and of β-dicarbonyl systems (cf. Dimroth and Schweizer, *Ber.*, 1923, **56**, 1375). The process involves a primary attack by lead tetra-acetate on the enolic form of the carbonyl compound, and the products isolated are then determined by the further reactions of the intermediate carbonyl radical.

SIMPLE ketones, *e.g.*, acetone and acetophenone, readily form the corresponding acyloin acetate on treatment with lead tetra-acetate in hot acetic acid (Dimroth and Schweizer, *Ber.*, 1923, **56**, 1375). This process has not been used generally for the synthesis of acyloins (cf. McElvain, "Organic Reactions," Vol. IV, Wiley and Sons, New York, 1948, p. 256) although it has been used, with advantage, in the preparation of mixed benzoins from the corresponding deoxybenzoin (Badcock, Cavill, Robertson, and Whalley, *J.*, 1950, 2961). As the present investigation is primarily concerned with the mechanism of such oxidations, simple carbonyl compounds, including some previously reported by Dimroth and Schweizer (*loc. cit.*), have been studied.

*cyclo*Hexanone is oxidised in acetic acid at 80° (no reaction at room temperature) to form 2-acetoxy*cyclo*hexanone, whilst *cis*-2 : 6-diacetoxy*cyclo*hexanone is obtained as an additional product in benzene solution or in excess of substrate. The structure and configuration of this compound are confirmed by its catalytic reduction and acid hydrolysis to *cis-cyclo*hexane-1 : 2 : 3-triol (Posternak and Ravenna, *Helv. Chim. Acta*, 1947, **30**, 441). In benzene, at 80°, acetophenone and ethyl malonate yield the α-acetoxy-derivatives as the sole oxidation products, whereas diethyl ketone gives a mixture of 1-acetoxy- and 1 : 1'-diacetoxy-diethyl ketone (cf. Dimroth and Schweizer's reactions in acetic acid). The 1-acetoxy-ketone is readily converted into the osazone; the structure of the diacetoxy-ketone is confirmed by its reduction and acetylation to a pentane-2 : 3 : 4-triol acetate (Reif, *Ber.*, 1908, **41**, 2739). Since 2-acetoxy*cyclo*hexanone is further oxidised, it appears that diacetoxy-compounds result from an attack by lead tetra-acetate at a second active centre in the monoacetoxy-derivative; disubstitution at the same carbon atom has not been noted. Although oxidation is slower in benzene than in acetic acid, the yields of acetoxylated products are considerably greater.

Ichikawa and Yamaguchi (*J. Chem. Soc. Japan*, 1952, **73**, 415), who studied the kinetics of the reactions between lead tetra-acetate and acetone, and acetophenone and its *p*-chloro- and *p*-bromo-derivatives in acetic acid, note that the process is of first order with respect to the ketone and independent of the oxidant. In benzene–acetic acid the rate is proportional to $[AcOH]^{\frac{1}{2}}$. These results indicate that enolisation of the ketone is the rate-determining step. Similarly, ketones are attacked by other oxidants (*e.g.*, potassium permanganate, Drummond and Waters, *J.*, 1955, **497**) *via* the enolic form.

The ease of oxidation of β-diketones and β-oxo-esters supports the above hypothesis. In addition, the dimeric products isolated from these oxidations indicate a free-radical

* Parts II and III, *J.*, 1954, 3943; 1955, 1404.

mechanism. Thus ethyl acetoacetate, in benzene at 10°, readily gives ethyl α-acetoxyacetoacetate and ethyl αα′-diacetylsuccinate, m. p. 91—91·5° (cf. Dimroth and Schweizer, *loc. cit.*, who obtained the α-acetoxy-derivative and an unidentified compound, m. p. 95—101°). Similarly, oxidation of acetylacetone yields 3-acetoxypentane-2 : 4-dione and 3 : 4-diacetylhexane-2 : 5-dione.

Comparative studies with acetyl peroxide show that acetylacetone and acetophenone are not oxidised in benzene at room temperature, thereby demonstrating stability to acetate radicals. However, at 80°, acetylacetone yielded 3 : 4-diacetylhexane-2 : 5-dione, and acetophenone gave an unidentified oil. Kharasch, McBay, and Urry (*J. Amer. Chem. Soc.*, 1948, **70**, 1269) who had previously obtained dimeric products from the attack of acetyl peroxide at 130° on acetylacetone and *cyclo*hexanone and were unable to identify the products of oxidation of acetophenone, suggest that methyl radicals (from the thermal decomposition of acetyl peroxide) are responsible for these dehydrogenations. Such processes would involve an initial abstraction of hydrogen from the active methylene group of the ketonic form of the carbonyl compound.

The oxidation of carbonyl compounds by lead tetra-acetate, although free-radical in nature, clearly differs from the above processes, and the following mechanism is proposed :

$$R\cdot CH_2\cdot COR' \rightleftharpoons R\cdot CH{:}CR'\cdot OH \text{ (rate-determining)}$$

$$\text{Initiation : } R\cdot CH{:}CR'\cdot OH + Pb(OAc)_4 \longrightarrow \text{Complex}$$

$$\text{Complex} \longrightarrow R\cdot CH{:}CR'\cdot O\cdot + \cdot Pb(OAc)_3 + AcOH$$

$$R\cdot CH{:}CR'\cdot O\cdot \rightleftharpoons R\cdot\dot{C}H\cdot CO\cdot R' \qquad \cdot Pb(OAc)_3 \rightleftharpoons \cdot OAc + Pb(OAc)_2$$

$$\text{Propagation : } R\cdot\dot{C}H\cdot CO\cdot R' + Pb(OAc)_4 \longrightarrow AcO\cdot CHR\cdot CO\cdot R' + \cdot Pb(OAc)_3$$

$$\text{Termination : (i) } R\cdot\dot{C}H\cdot CO\cdot R' + \cdot OAc \longrightarrow AcO\cdot CHR\cdot CO\cdot R'$$

$$\text{(ii) } 2R\cdot\dot{C}H\cdot COR' \longrightarrow (R'\cdot CO\cdot CHR\cdot)_2$$

The failure to isolate dimeric products from the oxidation when the percentage of enol is very small is not inconsistent with the proposed mechanism, as termination (i) takes charge. The lead tetra-acetate, which is always in excess, would readily effect the transformation of the carbonyl radicals available into the corresponding acetoxy-derivative. However, dimeric products are isolated [termination (ii)] from the oxidation of β-dicarbonyl systems in which the percentage of enol and the rate of enolisation are appreciable. These features are summarised in the annexed Table :

		Lead tetra-acetate oxidation products	
Compound	Enol (%) (in liquid)	Acetoxy	Dimeric
Ethyl malonate	0·01 [b]	Mono	—
*cyclo*Hexanone	0·02 [a]	Mono and di	—
Acetophenone	0·025 [c]	Mono	—
Triethoxycarbonylmethane	0·2 [b]	?	+
Ethyl acetoacetate	7·5 [a]	Mono	+
Acetylacetone	80·4 [a]	Mono	+

[a] Ingold, "Structure and Mechanism in Organic Chemistry," Cornell University Press, Ithaca, 1953, pp. 530 *et seq.* [b] Meyer, *Ber.*, 1912, **45**, 2852. [c] Smith and Guss, *J. Amer. Chem. Soc.*, 1937, **59**, 804.

The above mechanism for the oxidation of carbonyl compounds with lead tetra-acetate has obvious similarities to that postulated for the oxidation of phenols (cf. Part I, *J.*, 1954, 2785).

Cavill, Dean, McGookin, Marshall, and Robertson (*J.*, 1954, 4573) reported the conversion of chromanones into the 3-acetoxy-derivatives, whilst flavanones give a mixture in

which the flavone is invariably present, and the corresponding *iso*flavone and/or 3-acetoxyflavanone may be additional products. The present studies thus confirm the suggestion that the acetoxylation of chromanones and flavanones in the 3-position proceeds by a free-radical process, whilst attack at the 2-position in the latter series may be compared with the oxidation of toluene derivatives and benzyl ethers (cf. Parts II and III, *locc. cit.*).

Experimental

Light petroleum had b. p. 60—80°.

Carbonyl compounds were purified by distillation, then treated with ferrous sulphate, dried ($MgSO_4$), and redistilled. Acetic acid was purified by Orton and Bradfield's method (*J.*, 1924, **125**, 960). Lead tetra-acetate was prepared as in Part II.

Oxidation of cyclo*Hexanone.*—(*a*) *cyclo*Hexanone (19·6 g.) with lead tetra-acetate (88·6 g.) in acetic acid (150 ml.) was heated at 80° (bath) until no positive test for the oxidant (starch–iodide) was obtained (2 hr.). Acetic acid was distilled from the mixture, and the residue extracted with ether (3 × 50 ml.). The ethereal layer was washed with water, sodium hydrogen carbonate solution, and water, dried ($MgSO_4$), and evaporated. Distillation under reduced pressure gave unchanged *cyclo*hexanone, b. p. 54—58°/11 mm., n_D^{20} 1·4497, and 2-acetoxy*cyclo*hexanone (8·0 g.), b. p. 99—100°/6 mm., prisms, m. p. 40—41° (from light petroleum) (Found : C, 61·6; H, 7·7. Calc. for $C_8H_{12}O_3$: C, 61·5; H, 7·75%). Bergmann and Gierth (*Annalen*, 1926, **448**, 48) record m. p. 41—42°.

(*b*) *cyclo*Hexanone (19·6 g.) and lead tetra-acetate (88·6 g.) in benzene (150 ml.; freshly distilled from sodium) were heated at 80° until no test for the oxidant was obtained (8 hr.). The mixture was washed with water (4 × 50 ml.), and the organic layer separated and dried ($MgSO_4$). Removal of solvent, and then distillation under reduced pressure, yielded *cyclo*hexanone (3·6 g.), b. p. 67—70°/15 mm., n_D^{20} 1·4499, and 2-acetoxy*cyclo*hexanone (19·0 g.), b. p. 123—126°/16 mm., prisms, m. p. 39—40° (from light petroleum) (Found : C, 61·2; H, 7·4%). Further distillation gave *cis*-2 : 6-diacetoxy*cyclo*hexanone (1·1 g.), b. p. 158—160°/10 mm., needles, m. p. 145—146° (from light petroleum) (Found : C, 56·1; H, 6·35. $C_{10}H_{14}O_5$ requires C, 56·1; H, 6·6%). Posternak and Ravenna (*loc cit.*) report m. p. 147—148°. Hydrogenation (Adams catalyst) of this compound, followed by acid hydrolysis, gave *cis-cyclo*hexane-1 : 2 : 3-triol, purified by recrystallisation from alcohol and isolated as needles, m. p. 145—146°, from ethyl acetate (Found : C, 54·7; H, 9·2. Calc. for $C_6H_{12}O_3$: C, 54·5; H, 9·15%). A mixed m. p. of the *cis*-triol with *cis-cyclo*hexane-1 : 2 : 3-triol, kindly supplied by Professor T. Posternak, gave no depression.

(*c*) *cyclo*Hexanone (126 g., large excess) with lead tetra-acetate (88·6 g.), treated as in (*b*) (2 hr.), gave *cyclo*hexanone (104 g.), b. p. 50—52°/14 mm., n_D^{20} 1·4489, 2-acetoxy*cyclo*hexanone (12·0 g.), b. p. 112—114°/9 mm., prisms, m. p. 39—40° (from light petroleum) (Found : C, 61·6; H, 7·65%), and *cis*-2 : 6-diacetoxy*cyclo*hexanone (1·1 g.), b. p. 150—152°/9 mm., needles, m. p. 145—146° (from light petroleum) (Found : C, 56·3; H, 6·5%).

Oxidation of 2-*Acetoxy*cyclo*hexanone.*—2-Acetoxy*cyclo*hexanone (15·6 g.) and lead tetra-acetate (44·3 g.) in benzene (75 ml.) were heated at 80° (14 hr.). The mixture, worked up as in (*b*), yielded 2-acetoxy*cyclo*hexanone (7·0 g.), b. p. 110—120°/8 mm., m. p. and mixed m. p. 40—41°, and *cis*-2 : 6-diacetoxy*cyclo*hexanone (5·0 g.), b. p. 152—160°/8 mm., plates, m. p. 147—148° (from alcohol) (Found : C, 56·0; H, 6·7%).

Oxidation of Acetophenone.—(*a*) Acetophenone (11·0 g.) and lead tetra-acetate (44·3 g.) in benzene (75 ml.) were heated at 80° as above (9 hr.). The mixture, worked up as in (*b*), gave acetophenone (4·0 g.), b. p. 50—56°/2 mm., n_D^{20} 1·5346, and ω-acetoxyacetophenone (8·2 g.), b. p. 110—114°/2 mm., prisms, m. p. 46° (from light petroleum) (Found : C, 67·7; H, 5·7. Calc. for $C_{10}H_{10}O_3$: C, 67·4; H, 5·7%). Hunnius (*Ber.*, 1877, **10**, 2006) records m. p. 40°, and Nef (*Annalen*, 1904, **335**, 268) m. p. 49°.

Oxidation of Ethyl Malonate.—Ethyl malonate (16·0 g.) was treated with lead tetra-acetate (44·3 g.) in benzene (75 ml.) (8 hr.), then worked up as described for acetophenone, giving diethyl α-acetoxymalonate (17·2 g.), b. p. 114—116°/5 mm., n_D^{20} 1·4263 (Found : C, 49·1; H, 6·2. Calc. for $C_9H_{14}O_6$: C, 49·5; H, 6·5%). Conrad and Brückner (*Ber.*, 1891, **24**, 2993) report b. p. 235—245°.

Oxidation of Diethyl Ketone.—Diethyl ketone (86·0 g.) with lead tetra-acetate (443 g.) in benzene (750 ml.) was oxidised (50 hr.), then worked up as above, to yield 1-*acetoxydiethyl ketone* (45·0 g.), b. p. 56—57°/3 mm., n_D^{20} 1·4181 (Found : C, 58·4; H, 8·5. $C_7H_{12}O_3$ requires C, 58·3;

H, 8·4%), and 1 : 1′-*diacetoxydiethyl ketone* (15·0 g.), b. p. 80°/1 mm. (Found : C, 54·1; H, 6·7. $C_9H_{14}O_5$ requires C, 53·5; H, 7·0%).

Acid hydrolysis of the 1-acetoxy-compound yielded 2-hydroxy-3-pentanone, identified as the osazone, yellow prisms, m. p. 166—167° (from alcohol) (Found : C, 72·7; H, 7·05; N, 20·0. Calc. for $C_{17}H_{20}N_4$: C, 72·8; H, 7·2; N, 20·0%). Von Peckmann (*Ber.*, 1888, **21**, 1411) records m. p. 166—167°. Hydrogenation (Adams catalyst) of 1 : 1′-diacetoxydiethyl ketone, then acetylation (acetic anhydride–sodium acetate), gave a pentane-2 : 3 : 4-triol triacetate, needles, m. p. 123—124° (from ether). Reif (*loc. cit.*) records m. p. 121°. Acid hydrolysis of the hydrogenation product yielded a pentane-2 : 3 : 4-triol, which, on treatment with lead tetra-acetate (2 mols.), gave acetaldehyde (1·3 mols.), isolated as the 2 : 4-dinitrophenylhydrazone, m.p. and mixed m.p. 163·5—164° (Found : N, 25·2. Calc. for $C_8H_8O_4N_4$: N, 25·0%).

Oxidation of Triethoxycarbonylmethane.—Triethoxycarbonylmethane (23·2 g.) (Adickes, Brunnert, and Lucker, *J. prakt. Chem.*, 1931, **130**, 163) and lead tetra-acetate (44·3 g.) in benzene (100 ml.) were heated at 80° (6 hr.). The colour changed to orange. The mixture, treated as above, yielded triethoxycarbonylmethane (20 g.), b. p. 110—112°/2 mm., m. p. and mixed m. p. 28°, then an oil (2·0 g.), b. p. 158—160°/4 mm. (Found : C, 54·6; H, 6·5%). The residue (1·1 g.) slowly solidified to yield hexaethoxycarbonylethane, plates, m. p. 101° (from light petroleum) (Found : C, 52·3; H, 6·5. Calc. for $C_{20}H_{30}O_{12}$: C, 51·9; H, 6·5%). Mulliken (*Amer. Chem. J.*, 1893, **15**, 530) reports m. p. 101°.

Oxidation of Ethyl Acetoacetate.—Lead tetra-acetate (44·3 g.) was slowly added (20 min.) to a solution of ethyl acetoacetate (13·0 g.) in benzene (75 ml.) at 10°. On each addition of oxidant a colour change to orange, fading to pale yellow, occurred. The oxidation was exothermic. The mixture, worked up in the usual manner, gave unchanged ester (3·5 g.), b. p. 80—90°/15 mm., n_D^{20} 1·4176, ethyl α-acetoxyacetoacetate (8·0 g.), a pale yellow oil, b. p. 120—22°/15 mm. (Found : C, 51·2; H, 6·55. Calc. for $C_8H_{12}O_5$: C, 51·1; H, 6·4%) (Dimroth and Schweizer, *loc. cit.*, report b. p. 118—125°/16 mm.), and ethyl αα′-diacetylsuccinate (2·2 g.), b. p. 148—150°/15 mm., prisms, m. p. 91—91·5° (from light petroleum) (Found : C, 55·7; H, 6·9. Calc. for $C_{12}H_{18}O_6$: C, 55·8; H, 7·0%). Morton and Rogers (*J.*, 1926, 713) record m. p. 92° for one form of ethyl αα′-diacetylsuccinate.

Oxidation of Acetylacetone.—Acetylacetone (30·0 g.) with lead tetra-acetate (133 g.) in benzene (225 ml.) was treated as above (identical colour changes, reaction instantaneous) to give 3-acetoxypentane-2 : 4-dione (12·0 g.), a pale yellow oil, b. p. 84—90°/7 mm. (Found : C, 52·9; H, 6·4. Calc. for $C_7H_{10}O_4$: C, 53·2; H, 6·3%), and 3 : 4-diacetylhexane-2 : 5-dione (4·8 g.), b. p. 130—132°/1 mm., prisms, 190—191° (from benzene–light petroleum) (Found : C, 60·5; H, 7·0. Calc. for $C_{10}H_{14}O_4$: C, 60·6; H, 7·1%). Combes (*Compt. rend.*, 1890, **111**, 422) gives b. p. 111°/21 mm. for 3-acetoxypentane-2 : 4-dione and Mulliken (*loc. cit.*) reports m. p. 191·2° for 3 : 4-diacetylhexane-2 : 5-dione.

Oxidations with Acetyl Peroxide.—(*a*) Acetylacetone (5·0 g.) in benzene (50 ml.) was added to acetyl peroxide (6·0 g.) in ether (100 ml.) (cf. Part III, *loc. cit.*). A positive test for the oxidant was still obtained after 30 hr. at room temperature. Ether was then distilled off and the temperature raised to 80° (negative test after 1 hr.). The mixture was washed with water (2 × 50 ml.) and dried ($MgSO_4$). Removal of benzene, followed by distillation under reduced pressure, gave 3 : 4-diacetylhexane-2 : 5-dione (1·0 g.), b. p. 148°/2 mm., prisms, m. p. 190° (from benzene–light petroleum) (Found : C, 60·8; H, 7·2%). A gum (3·0 g.) did not distil.

(*b*) Acetophenone (6·0 g.) in benzene (75 ml.) was added to acetyl peroxide (6·0 g.) in ether (100 ml.). The mixture, treated as for acetylacetone (4 hr.), gave an intractable gum.

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The Chemistry of Santonin. Part I. Some Rearrangement Products of the Santonins.

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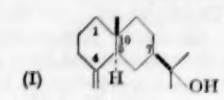
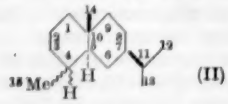
The acetates of two new desmotroposantonins (*trans*-fused lactones) have been prepared by the reaction of santonin and 11β(H)-santonin * with a mixture of acetyl chloride and acetic anhydride. The constitutions of the other products of these reactions are discussed. 11β(H)-Santonin has been converted into santonin.

ALTHOUGH the absolute configurations of the two known naturally occurring santonins have not yet been rigidly established, it is most probable from molecular-rotation data (Corey, *J. Amer. Chem. Soc.*, 1955, **77**, 1044; Abe and Sumi, *Chem. and Ind.*, 1955, 253) that their configurations at $C_{(7)}$ and $C_{(10)}$ are as in eudesmol (I) (Riniker, Kalvoda, Arigoni, Fürst, Jeger, Gold, and Woodward, *J. Amer. Chem. Soc.*, 1954, **76**, 313), and that santonin (III) and 11β(H)-santonin (IV) have the configurations shown (Corey, *loc. cit.*; Woodward

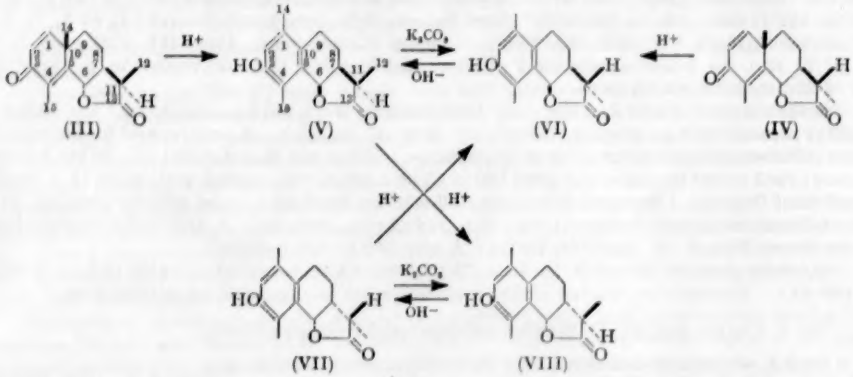


(I)



(II)

and Yates, *Chem. and Ind.*, 1954, 1391; Abe, Harukawa, Ishikawa, Miki, Sumi, and Toga, *J. Amer. Chem. Soc.*, 1953, **75**, 2567; *Proc. Japan Acad.*, 1952, **28**, 425; 1953, **29**, 113; 1954, **30**, 119; Matsui, Toki, Kitamura, Suzuki, and Hamuro, *Bull. Chem. Soc. Japan*, 1954, **27**, 7; Cocker and McMurry, *Chem. and Ind.*, 1954, 1199; Cocker, *Ann. Reports*, 1954, **51**, 209). The acid-catalysed isomerisation of these two santonins under mild conditions involves inversion at $C_{(6)}$ so that the desmotropo-compounds so produced,



(III) (V) (VI) (IV)

(VII) (VIII)

namely, (V) and (VI), respectively, are *cis*-fused lactones (Huang-Minlon, *J. Amer. Chem. Soc.*, 1948, **70**, 611) with the absolute configurations shown. These desmotropo-compounds can be isomerised by various treatments so that of the eight possible isomeric forms, all four *cis*-fused lactones (V—VIII) have been described (Huang-Minlon, *loc. cit.*; Chopra, Cocker, and Edward, *Chem. and Ind.*, 1955, **41**, who also give references to earlier work).

Nomenclature of the Desmotroposantonins.—The nomenclature of these compounds is

* The nomenclature and numbering are as suggested by Cocker and Cahn (*Chem. and Ind.*, 1955, 384). The root name, desmotroposantonin, is retained for the butanolides obtained from the santonins with acidic reagents. The non-aromatic compounds lacking a butanolide ring are named after the parent hydrocarbon, eudesmane (II), with the absolute configuration shown.

confused, but in the more rational system of Huang-Minlon (*loc. cit.*; cf. Simonsen "The Terpenes," Cambridge Univ. Press, 1952, Vol. III, p. 263), the primary rearrangement products (V) of santonin, and (VI) of 11β(H)-santonin, are respectively named (−)α- and (−)β-desmotroposantonin. Their enantiomorphs (VII) and (VIII) are (+)α- and (+)β-desmotroposantonin, respectively. It is now proposed to name the desmotropo-compounds according to their absolute configuration as shown below.

(−)α-Desmotroposantonin	(V)	= 6α(H),7α(H),11α(H)-Desmotroposantonin
(−)β-Desmotroposantonin	(VI)	= 6α(H),7α(H),11β(H)- "
(+)α-Desmotroposantonin	(VII)	= 6β(H),7β(H),11β(H)- "
(+)β-Desmotroposantonin	(VIII)	= 6β(H),7β(H),11α(H)- "

The proposed system, whilst it does not state the direction of optical rotation of the desmotropo-compounds, otherwise gives a full description of their stereochemistry.

New Desmotroposantonins.—We have now obtained under mildly acidic conditions the acetates of two of the four remaining isomeric desmotroposantonins, in which the lactone rings are *trans*-fused. Treatment of santonin (III) with a mixture of acetyl chloride and acetic anhydride (cf. Westphal, *Ber.*, 1937, **70**, 2128; Inhoffen, *Ber.*, 1936, **69**, 2141) afforded a mixture of two isomeric compounds, $C_{17}H_{20}O_4$, which proved to be the acetate (IX) of 6β(H),7α(H),11α(H)-desmotroposantonin and an unsaturated enol acetate (XI) discussed below.

The assignment of the structure of the new desmotropo-compound (IX) is based on the following facts. (1) Its ultraviolet absorption maxima are at 2720 (log ε 2·89) and 2800 Å (log ε 2·91). Gunstone and Tulloch (*J.*, 1955, 1130) record absorption in the range 2730—2810 Å (log ε 3·10) for the acetate of (V). (2) A 6β(H)-configuration is likely because the new lactone is dextrorotatory. The *cis*-fused dextrorotatory lactones (VII) and (VIII), and *hypo*santonin (IX; H for OAc) all have the 6β(H)-configuration (cf. Huang-Minlon, *loc. cit.*). (3) The compound (IX) displays the butanolide >C=O maximum at 1788 cm.$^{-1}$ (in $CHCl_3$) whilst we have found for the *cis*-fused lactone (V) a maximum at 1766 cm.$^{-1}$ (in $CHCl_3$). All the *cis*-fused butanolides we have examined exhibit >C=O stretching frequency at about 1765 cm.$^{-1}$ (in $CHCl_3$); many, but not all, *trans*-butanolides exhibit a >C=O band at 1785—1790 cm.$^{-1}$. (4) The *trans*-fusion of the lactone ring is proved by isomerisation of the compound to the acetate of the more stable *cis*-lactone (V) by the action of sulphuric acid in acetic anhydride (cf. Huang-Minlon, *loc. cit.*; Huang-Minlon, Lo, and Chu, *J. Amer. Chem. Soc.*, 1943, **65**, 1780). Similarly, hydrolysis of the acetate (IX) with methanolic potassium hydroxide and acidification of the solution affords the phenol (V). Inversion at $C_{(6)}$ occurs during acidification, a reaction analogous to the conversion of *hypo*santonic acid into *isohypo*santonin (V; H for OH) (cf. "Encyclopædia of Organic Chemistry," Elsevier Publ. Co., Amsterdam, Vol. XIIB, p. 3458). This is confirmed by the widely different molecular rotations of the potassium salts of the acids derived from (IX) and (V) (see Table 1). (5) The molecular-rotation contribution of the lactone ring in (IX) is *positive* (Table 1), due allowance being made for the contribution of the acetate residue. Klyne's rule (*Chem. and Ind.*, 1954, 1198) then indicates a 6β(H)-configuration when the molecule is orientated as in (IX).

Treatment of 11β(H)-santonin (IV) with acetyl chloride and acetic anhydride affords a small quantity of the acetate of the *trans*-lactone (X) together with larger quantities of the acetate of the *cis*-lactone, 6α(H),7α(H),11β(H)-santonin (VI), into which the isomer (X) is converted with the greatest ease. The new lactone (X), like the acetates of the other desmotropo-compounds, displays maximum absorption at 2720 (log ε 3·02) and 2800 Å (log ε 3·03). In the infrared region, however, it shows butanolide carbonyl stretching frequency at 1766 cm.$^{-1}$, rather than in the 1785—1790 cm.$^{-1}$ range expected of a *trans*-lactone. On treatment with acetic anhydride–sulphuric acid, it is transformed into the acetate of 6α(H),7α(H),11β(H)-santonin (VI). The instability of the lactone (X) serves to indicate the lower stability of the 11β(H)-configuration in the *trans*-fused lactone system in which $C_{(7)}$ has the α(H)-configuration. This fact is further demonstrated by the conversion of 11β(H)-santonin (IV) into santonin (III) by treatment of the former with anhydrous potassium carbonate in boiling xylene (cf. Chopra, Cocker, and Edward, *loc. cit.*). Whilst this conversion takes place in 45% yield only, similar treatment of santonin leads to 45%

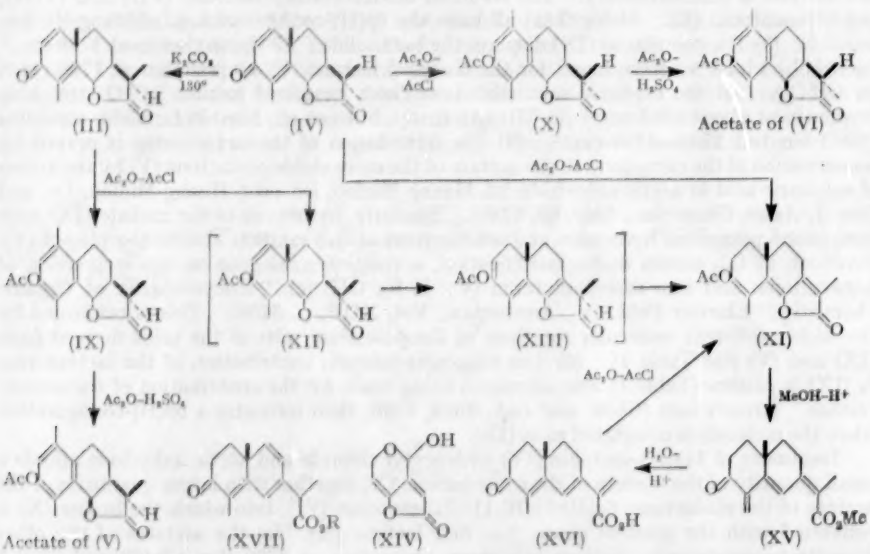
recovery, and in both cases charring accounts for the losses. In the *cis*-lactones the reverse order of stabilities is found (Woodward and Yates; also Chopra, Cocker, and Edward, *locc. cit.*). Examination of molecular models shows that in a *cis*-fused lactone such as (V) with 11α(H)-configuration the 11-methyl group directly opposes the 8-methylene group, and further that in this arrangement the 11-methyl group is *cis* with respect to the

TABLE 1. *Molecular-rotation contributions of lactone rings.*

Substance	Lactone, $[M]_D$	Acid, $[M]_D$	$\Delta[M]_D$	Ref.
Santonin (III)	−425° (EtOH)	−68° (EtOH)	−357°	*a*
11β(H)-Santonin (IV)	−342 (MeOH)	−234 (K salt in MeOH)	−108	
(V)	−344 (EtOH)	+186 (EtOH)	−530	*b*
		−130 (K salt in MeOH)	−214	
Acetate of (V)	−376 ($CHCl_3$)	—	—	
(VI)	−261 (EtOAc)	+134	−395	*b*
(VII)	+320 (EtOH)	−184	+504	*b*
(VIII)	+261 (EtOH)	−213	+393	*b*
(IX)	+247 ($CHCl_3$)	−132 —	—	
(IX, OH for OAc) (est.)	+243	+ 95 (K salt in MeOH)	+148	

(*a*) Hesse, *Annalen*, 1875, **176**, 89, 125. (*b*) Chopra, Cocker, and Edward, *loc. cit.* Klyne's rule (*loc. cit.*) confirms the configuration shown for lactones (V—VIII); it cannot be applied to santonin (III) and 11β(H)-santonin (IV); presumably the dienone system interferes.

non-hydrogen substituent atoms at $C_{(6)}$ and $C_{(7)}$. Obviously this is a less stable arrangement than that with the 11β(H)-configuration. In the *trans*-fused lactones there is no direct opposition between the groups attached to $C_{(11)}$ and the 8-methylene group. There is however greater interference between the 11-methyl and the carbonyl group when $C_{(11)}$ has the β- than when it has the α-configuration.



The second product of the action of acetyl chloride and acetic anhydride on santonin was a yellow compound which we formulate as the unsaturated enol acetate, 3-acetoxy-eudesma-3 : 5 : 7(11)-trien-6 : 13-olide (XI). The same compound was obtained in small yield by the action of carefully purified acetyl chloride and acetic anhydride on 11β(H)-santonin (IV). This second mode of preparation serves to exclude formulations such as (XII) and (XIII), since in these the original asymmetry at $C_{(11)}$ is retained. Since the preparation of the enol acetate takes place under conditions unlikely to epimerise $C_{(11)}$, structures (XII) and (XIII) would necessitate different products from santonin and 11β(H)-santonin. Structure (XI) is supported by spectroscopic evidence. Thus the enol acetate

exhibits ultraviolet maxima at 3300 (log ε 4·46) and 2190 Å (log ε 3·63) and an infrared peak at 1764 cm.$^{-1}$ (lactone and acetate-carbonyl), and a triplet around 1639 cm.$^{-1}$ which can be attributed to the triene system. It is interesting that the carbonyl frequency of the αβ-unsaturated lactone is increased rather than decreased by the extended conjugated system. However Grove (*J.*, 1951, 883) has shown that the carbonyl frequency of patulin (XIV), with a similar unsaturated system, is at 1768 cm.$^{-1}$.

The enol-acetate is unaffected by a mixture of sulphuric acid and acetic acid whereas a compound of structure (XII), and perhaps (XIII), would be expected to be rearranged to a desmotropo-compound by this reagent. Again these structures may be eliminated on spectroscopic grounds. If probable hypsochromic effects of the oxygen-substituents are neglected (Briggs and Cain, *J.*, 1954, 4182), a compound (XII) would be expected to show maximum absorption at 3080 Å and a compound (XIII) at about 3130 Å (cf. Fieser and Fieser, "Natural Products Related to Phenanthrene," Reinhold Publ. Corp., New York, 1949, p. 185).

Reaction of the enol acetate (XI) with N-methanolic hydrogen chloride affords a methyl ester, $C_{16}H_{20}O_3$ (XV), hydrolysed by aqueous mineral acid to an acid, $C_{15}H_{18}O_3$ (XVI). The last is reconverted into (XI) on being treated with acetyl chloride and acetic anhydride. Thus the three compounds have the same carbon skeleton. Further, the mild conditions of the reactions rule out very extensive migrations of the double bonds. The methyl ester, however, cannot have the disposition of the double bonds shown in (XVI) or (XVII) since it does not show a low-intensity maximum in the region 4700 Å due to a carbonyl group conjugated with a triene. Again the large difference in molecular rotation between the ester and acid (Table 2) indicates that the two cannot have the same disposition of double

TABLE 2.

Substance	Enol acetate (XI)	Me ester (XV)	Acid (XVI)
$[M]_D$	−697°	−1082°	−659°

The extended unsaturated system would be expected to give high negative values for $[M]_D$.

bonds. By exclusion the ester must be methyl 3-oxoeudesma-4(15) : 5 : 7(11)-trien-13-oate (XV), and in this structure the low-intensity maximum of the carbonyl group in the neighbourhood of 3200 Å is masked by the higher absorption of the conjugated triene-ester chromophore.

The acid obtained by hydrolysis of the ester shows a low-intensity absorption band at 4740 Å, indicative of a conjugated trienone, either (XVI) or (XVII). The latter formulation is however excluded since it is that of a βγ-unsaturated acid, which should readily be decarboxylated, and the acid does not behave in this fashion. The acid is thus 3-oxoeudesma-4 : 6 : 11-trien-13-oic acid (XVI).

Table 3 sets out the spectroscopic characteristics of ester (XV), acid (XVI), and ethyl methyleneacetoacetate, a vinylogue of (XV and XVI), and likewise a "crossed" enedione system.

TABLE 3.

	Ultraviolet max. (Å) (and log ε)					Infrared bands (cm.$^{-1}$)
Ester (XV)	3650	2940	2780	2375	—	1728 (br., s), αβ-unsat. ester & CO
	(4·5	3·58	3·59	3·60)	—	1631 (m), 1600 (m) triene
Acid (XVI)	4740	3725	2875	2755	2350	1730 (br., s), CO_2H & CO
	(1·60	4·50	3·65	3·67	3·65)	1630 (m), 1593 (m) triene
$CH_2{:}C(CO{\cdot}CH_3){\cdot}CO_2Et$ ...	3070 (infl.)		2390	—	—	1741 (s), CO_2Et
	(1·5		3·24)			1712 (s), CO
						1632 (m), $>C{:}CH_2$

It is interesting that the infrared absorptions of the ester and the acid are similar, but this is not surprising since one system is electronically the reverse of the other. It is also interesting that in all three systems the infrared spectra display carbonyl stretching frequencies at positions expected of isolated carbonyl groups. Indeed the frequencies appear to be somewhat enhanced. It might have been expected that the "crossed" ene-dione systems, like the "crossed" dienone system found in santonin, would have

behaved as two separate αβ-unsaturated carbonyl systems; in the ultraviolet region this appears to be the case, but the infrared spectra of both ester and acid are strongly reminiscent of those of an α-keto-ester and -acid.

Experimental

Ultraviolet spectra were measured for EtOH solutions with a Beckmann D.U. instrument, and the infrared spectra in $CHCl_3$ with a Hilger 800 Double-beam instrument. $[\alpha]_D$ refer to $CHCl_3$ solutions.

Acetate of 6β(H),7α(H),11α(H)-*Desmotroposantonin* (IX) *and* 3-*Acetoxyeudesma*-3 : 5 : 7(11)-*trien*-6 : 13-*olide* (XI).—A mixture of santonin (10 g.), acetic anhydride (20 c.c.), and acetyl chloride (20 c.c.) was refluxed for 2·5 hr. The reagents were then removed under reduced pressure, and the product was crystallised from ethanol, giving a mixture of well-formed needles and rhombs. These were separated by hand-picking, and each crystallised from ethanol, thus affording 6β(H),7α(H),11α(H)-*desmotroposantonin acetate* (5·4 g.) as colourless needles, m. p. 180°, $[\alpha]_D^{18}$ +85·8° (*c* 0·91) (Found: C, 70·4; H, 6·8. $C_{17}H_{20}O_4$ requires C, 70·8; H, 7·0%), and the "*enol acetate*" (XI) (2·5 g.) as yellow rhombs, m. p. 135°, $[\alpha]_D^{20}$ −242·0° (*c* 1·9) (Found: C, 70·3; H, 6·8. $C_{17}H_{20}O_4$ requires C, 70·8; H, 7·0%).

Action of Acetic Anhydride–Sulphuric Acid on 6β(H),7α(H),11α(H)-*Desmotroposantonin Acetate*.—The preceding compound (0·5 g.) was dissolved in acetic anhydride (8 c.c.), sulphuric acid (2 drops) was added, and the mixture was heated on the water-bath for 20 min. The product was poured into water, giving crude (0·46 g.) acetate of 6α(H),7α(H),11α(H)-desmotroposantonin (V) which after recrystallisation from ethanol had m. p. 155—156°, undepressed by an authentic specimen of this desmotropo-compound.

Hydrolysis of 6β(H),7α(H),11α(H)-*Desmotroposantonin Acetate* (IX).—A solution of this compound (1·0 g.) and potassium hydroxide (0·4 g.) in methanol (15 c.c.) was set aside for 24 hr. at room temperature. The product on acidification was 6α(H),7α(H),11α(H)-desmotroposantonin (V) (0·62 g.), m. p. and mixed m. p. 194°.

Methyl 3-*Oxoeudesma*-4(15) : 5 : 7(11)-*trien*-13-*oate* (XV).—The enol acetate (XI) (1 g.) was heated with methanolic hydrochloric acid (N; 10 c.c.) until it dissolved and the solution was set aside for 1 hr. The solid which had been deposited was collected (0·65 g.) and crystallised from methanol, giving the *ester* (XV) as pale yellow needles, m. p. 150—151°, $[\alpha]_D^{20}$ −416·1° (*c* 0·92) [Found: C, 74·3; H, 7·8; OMe, 12·1%; *M* (Rast), 267. $C_{16}H_{20}O_3$ requires C, 73·8; H, 7·7; OMe, 11·9%; *M*, 260].

3-*Oxoeudesma*-4 : 6 : 11-*trien*-13-*oic Acid* (XVI).—A solution of the above ester (0·1 g.) in 50% aqueous-methanolic hydrogen chloride (0·5N; 10 c.c.) was warmed at 50° for 1 hr. and cooled. The *acid* (0·07 g.; m. p. 170—171°) was collected and crystallised from ethanol as pale yellow needles, m. p. 176—177°, $[\alpha]_D^{20}$ −268° (*c* 0·52) (Found: C, 72·8; H, 7·4. $C_{15}H_{16}O_3$ requires C, 73·1; H, 7·4%).

Reconversion of 3-*Oxoeudesma*-4 : 6 : 11-*trien*-13-*oic Acid* (XVI) *into the Enol Acetate* (XI).—The acid (XVI) (0·5 g.) was refluxed with acetic anhydride (5 c.c.) and acetyl chloride (5 c.c.) for 3·5 hr. The product (0·46 g.), m. p. 134°, was the enol acetate (XI).

Experiments with 11β(H)-*Santonin*.—*Santonin from* 11β(H)-*santonin*. 11β(H)-Santonin (1 g.), anhydrous potassium carbonate (1 g.), and xylene (12·5 c.c.) were refluxed for 24 hr. (cf. Cocker, Cross, and Lipman, *J.*, 1949, 959). After refluxing with charcoal, filtration, and removal of solvent, the product (0·45 g.) had m. p. 158—165°. Crystallisation from ethanol gave santonin, m. p. and mixed m. p. 169—171°, $[\alpha]_D^{17}$ −171·5° (*c* 1·35).

6β(H),7α(H),11β(H)-*Desmotroposantonin acetate* (X). (*a*) A solution of 11β(H)-santonin (5 g.) in acetic anhydride (10 c.c.), and acetyl chloride (10 c.c.) were refluxed for 3·5 hr. The main product was 6α(H),7α(H),11β(H)-desmotroposantonin acetate (VI) (4·3 g.), m. p. and mixed m. p. 155—156°, together with unchanged 11β(H)-santonin (0·35 g.).

(*b*) In a similar experiment but with purified acetyl chloride, 11β(H)-santonin (4·2 g.) was recovered together with the enol acetate (XI) (0·13 g.), m. p. and mixed m. p. 134—135°.

(*c*) In a further experiment 6α(H),7α(H),11β(H)-desmotroposantonin acetate (3·4 g.) was isolated, together with 6β(H),7α(H),11β(H)-*desmotroposantonin acetate* (X) (0·6 g.) as plates, m. p. 116°, $[\alpha]_D^{21}$ +12·6° (*c* 1·2) (Found: C, 70·6; H, 6·9. $C_{17}H_{20}O_4$ requires C, 70·8; H, 7·0%). Crystallisation of this compound from alcohol gave a second form (needles), m. p. 124—125° (Found: C, 70·9; H, 7·1%). A mixture of the two forms had m. p. 116—117°. Light absorption max. of both forms: 2800, 2720 Å (log ε 3·03, 3·02).

Rearrangement of the acetate (X). The acetate (0·15 g.) was heated with acetic anhydride

(2 c.c.) and concentrated sulphuric acid (1 drop) for 20 min. The product was the crude acetate (0·12 g.) of 6α(H),7α(H),11β(H)-desmotroposantonin (VI) and after crystallisation from ethanol had m. p. and mixed m. p. 154—155°.

Ethyl Methyleneacetoacetate.—Ethyl acetoacetate (10 g.) was added to a mixture of formaldehyde (10 c.c., 40%), and crystalline sodium acetate (2 g.). Alcohol was then added, dropwise, with cooling, until the mixture was homogeneous (cf. Nakazawa and Matsuura, *J. Pharm. Soc. Japan*, **1951**, **71**, 178, who give no physical constants for the product). After 1 hr. the product was poured into water and extracted with ether, and the extract washed several times with water. After drying, the product was twice distilled, giving a colourless oil (2·5 g.), b. p. 176—177°/38 mm., $n_D^{19\cdot5}$ 1·4522 (Found: C, 58·7; H, 7·5. $C_7H_{10}O_3$ requires C, 59·1; H, 7·1%).

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Synthetic and Oxidative Studies in the Polyhydroxydiphenyl Series. Part I.

By J. MALCOLM BRUCE and F. K. SUTCLIFFE.

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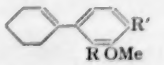
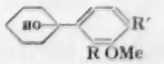
2 : 3-Dihydroxy- and 2 : 3 : 4-trihydroxy-diphenyl have been prepared from organometallic compounds and *cyclo*hexanone. Oxygenation of 2 : 3-dihydroxydiphenyl in a phosphate buffer at pH 8 gives only amorphous material, but treatment with silver oxide in ether yields the deeply coloured 2 : 3-diphenylbenzoquinone. Oxidation of 2 : 3 : 4-trihydroxydiphenyl in aqueous media yields a compound believed to be a diphenylpurpurogallin, probably 2′ : 3′ : 4′ : 4-tetrahydroxy-1′ : 5-diphenylbenz*ocyclo*heptatrien-3-one. The syntheses of several new derivatives of catechol and pyrogallol are described.

FOR a study of the mechanism of autoxidation of 5 : 6-dihydroxyindole (cf. Bruce, *Chem. and Ind.*, 1954, 310; *J. Appl. Chem.*, 1954, **4**, 469) we require certain indolyl derivatives of *vic.*-polyhydric phenols in which the heterocyclic ring is adjacent to a hydroxyl group. Before the preparation of these compounds, however, we found it necessary to investigate the synthesis, from organometallic compounds and *cyclo*hexanone, of some related polyphenols in which the indole nucleus is replaced by a phenyl group, and in the present paper the preparation and certain oxidative properties of 2 : 3-dihydroxy- and 2 : 3 : 4-trihydroxy-diphenyl are described.

1-(2 : 3-Dimethoxyphenyl)*cyclo*hexene (I) was prepared from 3-lithioveratrole and *cyclo*hexanone *via* the *tert.*-alcohol (IV) as described by Bergmann, Pappo and Ginsburg (*J.*, 1950, 1369) and Ginsburg and Pappo (*J.*, 1950, 516), and on dehydrogenation with chloranil in xylene it afforded 2 : 3-dimethoxydiphenyl from which 2 : 3-dihydroxydiphenyl was obtained in excellent yield by demethylation with aluminium chloride in chlorobenzene (cf. Dawson, Wasserman and Keil, *J. Amer. Chem. Soc.*, 1946, **68**, 534; Mason, *ibid.*, 1947, **69**, 2241).

(I) R = OMe; R′ = H
(II) R = H; R′ = OMe
(III) R = R′ = OMe





(IV) R = OMe; R′ = H
(V) R = H; R′ = OMe
(VI) R = R′ = OMe

Bergmann, Pappo, and Ginsburg (*loc. cit.*) based the orientation of compounds (I) and (IV) on the observation by Gilman, Swiss, and Cheney (*ibid.*, 1940, **62**, 1963) that metallation of veratrole with *n*-butyl-lithium in ether and subsequent carboxylation yielded 70% of 2 : 3-dimethoxybenzoic acid, indicating that the metal atom enters the veratrole nucleus

in a position adjacent to a methoxyl group. In the present work this orientation has been confirmed by the synthesis, from 4-iodoveratrole, of the isomeric 1-(3 : 4-dimethoxyphenyl)*cyclo*hexanol (V) and the corresponding *cyclo*hexene (II), the physical properties of which differ considerably from those of (IV) and (I) respectively.

4-Iodoveratrole was readily prepared in over 70% yield from veratrole by treatment with iodine and mercuric oxide at 95°. By effecting the iodination in the presence of alcohol at room temperature Seer and Karl (*Monatsh.*, 1913, **34**, 647) and Ritchie (*J. Proc. Roy. Soc. N.S.W.*, 1945, **78**, 134) obtained yields of 31% and 56% respectively.

Attempts to prepare the 4-iodomagnesium derivative of veratrole were unsuccessful and consequently 4-lithioveratrole was prepared from 4-iodoveratrole by cross-metallation with phenyl-lithium. Reaction of 4-lithioveratrole with an excess of *cyclo*hexanone under the usual conditions afforded 1-(3 : 4-dimethoxyphenyl)*cyclo*hexanol (V), which was readily dehydrated to the *cyclo*hex-1-ene (II), and a quantity of 2-*cyclo*hexylidene*cyclo*hexanone.

Oxygenation of dilute solutions of 2 : 3-dihydroxydiphenyl in a phosphate buffer at pH 8 yielded only brown amorphous material; there was no indication of intramolecular reaction. Oxidation with silver oxide in anhydrous ether gave 2 : 3-diphenylbenzoquinone (VII), m. p. 92—94°, as deep brown crystals which had a green reflex. In aqueous-alcoholic solution the quinone decomposed to a dark polymer, the reaction being catalysed by acids and bases. Silver oxide oxidation of 3 : 4-dihydroxydiphenyl (Norris, Macintire, and Corse, *Amer. Chem. J.*, 1903, **29**, 120) yielded 3 : 4-diphenylbenzoquinone (VIII) as deep reddish-brown crystals, m. p. 105·5—107·5°.

Solutions of 2 : 3- and 3 : 4-diphenylbenzoquinones in dioxan showed light absorption maxima which slowly decreased in intensity and moved to slightly shorter wavelengths when the solutions were preserved in the dark at room temperature in the presence of air. Similar, though very much more pronounced, spectral shifts were observed by Mason (*J. Amer. Chem. Soc.*, 1948, **70**, 138) for solutions of 1 : 2-benzoquinone and its 3-*n*-pentadecyl derivative. In the solid state both diphenoquinones were spectroscopically almost unchanged after two months' storage in the dark at room temperature.

In the pyrogallol series, 1-(2 : 3 : 4-trimethoxyphenyl)*cyclo*hexanol (VI) was prepared from pyrogallol trimethyl ether by metallation with *n*-butyl-lithium and subsequent reaction of the 4-lithio-compound with *cyclo*hexanone as described by Ginsburg and Pappo (*ibid.*, 1953, **75**, 1094), but better yields were obtained when 4-lithiopyrogallol trimethyl ether was prepared by halogen–metal interchange between phenyl-lithium and 4-bromopyrogallol trimethyl ether.

Pyrogallol trimethyl ether was brominated by treatment with bromine in carbon tetrachloride, this method giving good yields and being more convenient than the procedures of Kohn *et al.* (*Monatsh.*, 1925, **46**, 85; 1928, **49**, 178). Upon nitration as described by Kohn and Grün (*loc. cit.*, 1925) the bromo-compound yielded 4-bromo-5 : 6-dinitropyrogallol trimethyl ether whose orientation was established by reduction with zinc and acetic acid; the resulting diamine, which was not isolated, condensed readily with 9 : 10-phenanthraquinone to yield 10-bromo-11 : 12 : 13-trimethoxydibenzo[*a*, *c*]phenazine, and with benzil to give 5-bromo-6 : 7 : 8-trimethoxy-2 : 3-diphenylquinoxaline.

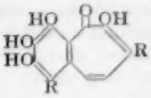
The *tert.*-alcohol (VI) prepared by either of the above procedures crystallised from light petroleum in rhombic platelets, m. p. 65°, in good agreement with the properties reported by Ginsburg and Pappo (*loc. cit.*). However, a preparation by halogen–metal interchange gave a dimorphic form which crystallised from light petroleum in short thick needles, m. p. 79·5°. This material was isolated from all subsequent preparations. On dehydration as described by Ginsburg and Pappo (*loc. cit.*), both forms yielded the *cyclo*hex-1-ene (III).

2 : 3 : 4-Trimethoxydiphenyl was prepared in 81% yield by dehydrogenation of the *cyclo*hexene (III) with chloranil; dehydrogenation with sulphur or palladium–charcoal gave lower yields. Demethylation, preferably with aluminium chloride in chlorobenzene, afforded 2 : 3 : 4-trihydroxydiphenyl, which crystallised from xylene under nitrogen in colourless blades. In air this compound slowly developed a violet colour which could only be removed by sublimation at reduced pressure; the change occurred more rapidly

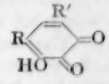
when the polyphenol was dissolved in hydrocarbons. A similar effect was observed by Campbell (*J. Amer. Chem. Soc.*, **1951**, **73**, 4190) in the case of **4 : 6-di-*tert.*-butylpyrogallol.**

Owing to the low solubility of **2 : 3 : 4-trihydroxydiphenyl** in water, oxidation was conducted in aqueous dioxan. Sodium iodate as oxidant afforded a **13%** yield of golden-orange needles, m. p. **211°**, which dissolved readily in **0·5%** aqueous sodium hydroxide with an intense blue colour which in the air soon became green and then yellow. Very

(VII) R = Ph; R′ = H
(VIII) R = H; R′ = Ph



(IX) R = H
(X) R = Me
(XI) R = Ph



(XII) R = Ph; R′ = H
(XIII) R = H; R′ = Ph

similar colour reactions are given by both purpurogallin (IX) and dimethylpurpurogallin (X), suggesting that the product is diphenylpurpurogallin (XI), and this view is supported by the similarity of the absorption spectra of the three compounds.

Yields of up to **70%** of pure diphenylpurpurogallin were obtained when solutions of **2 : 3 : 4-trihydroxydiphenyl** in aqueous dioxan containing a little sodium hydrogen carbonate or disodium hydrogen phosphate were oxidised with molecular oxygen. It is of interest that the product precipitated under these conditions consisted of small brick-red needles which when slowly heated had the same melting point as diphenylpurpurogallin prepared by iodate oxidation, but when placed on a block preheated to **117°** melted completely and then rapidly re-solidified; on rise of temperature the normal melting point was observed. The primary melting appeared to occur without chemical change, suggesting that diphenylpurpurogallin is dimorphic. The change to the stable form took place extremely slowly in the solid state at room temperature, but quite rapidly in non-polar, and almost instantaneously in polar, solvents.

When **2 : 3 : 4-trihydroxytoluene** was oxidised under similar conditions pure dimethylpurpurogallin (X), identical with material prepared by iodate oxidation as described by Critchlow, Haworth, and Pauson (*J.*, 1951, 1318), was precipitated in **50%** yield as small orange needles which did not show a double melting point.

It is therefore apparent, if the mechanism postulated by Critchlow, Haworth, and Pauson (*loc. cit.*) for the formation of purpurogallin from pyrogallol is correct, that the first stage in the oxidation of **2 : 3 : 4-trihydroxydiphenyl** under the above conditions must be the formation of **2-hydroxy-3 : 4-diphenoquinone** (XII) and not of **4-hydroxy-2 : 3-diphenoquinone** (XIII).

Experimental

Reactions with organolithium compounds were carried out under oxygen-free nitrogen. The term (c) indicates that crystallisation was effected by cooling of the solution, prepared at room temperature, in solid carbon dioxide–acetone. Absorption spectra were measured in dioxan in a Unicam SP.500 spectrophotometer. M. p.s are corrected.

2 : 3-*Dimethoxydiphenyl*.—A mixture of **1-(2 : 3-dimethoxyphenyl)*cyclo*hexene** (Bergmann, Pappo, and Ginsburg, *loc. cit.*) **(21 g.)**, chloranil (47·5 g.), and dry xylene **(220 c.c.)** was refluxed for 8 hr., cooled, and filtered from tetrachloroquinol. The filtrate was washed with **10%** aqueous sodium hydroxide and water, and dried (Na_2SO_4). Removal of the solvent left a deep red-brown oil which was distilled and the fraction with b. p. **100°/0·2 mm.** was crystallised (c) from light petroleum (b. p. **40—60°**), giving **2 : 3-*dimethoxydiphenyl*** **(11·2 g., 54%)** as colourless needles, m. p. **46°** (Found: C, 78·4; H, 6·3. $C_{14}H_{14}O_2$ requires C, 78·5; H, 6·5%).

2 : 3-*Dihydroxydiphenyl*.—**2 : 3-Dimethoxydiphenyl (10·4 g.)** was dissolved in dry chlorobenzene **(120 c.c.)**, powdered anhydrous aluminium chloride **(12·5 g.)** added, and the mixture was refluxed for **3½ hr.**, then cooled, poured into ice-cold **15%** hydrochloric acid **(350 c.c.)**, and extracted with ether. The extract was washed with water and dried (Na_2SO_4). Removal of the solvent left a grey solid which was washed with cold light petroleum (b. p. **40—60°**) and sublimed from the melt at **110°/0·05 mm.**, to give a colourless microcrystalline powder **(8·4 g., 95%)** which upon crystallisation from light petroleum (b. p. **80—100°**) afforded **2 : 3-dihydroxydiphenyl as colourless needles, m. p. 114°** (Loudon and Scott, *J.*, **1953**, **265**, **report m. p. 111°**)

(Found: C, 77·5; H, 5·3. Calc. for $C_{12}H_{10}O_2$: C, 77·4; H, 5·4%). The *diacetate* separated from benzene–light petroleum (b. p. 60—80°) in thick needles, m. p. 79—79·5° (Found: C, 70·9; H, 5·2; Ac, 31·1. $C_{16}H_{14}O_4$ requires C, 71·1; H, 5·2; Ac, 31·9%). Light absorption: 2 : 3-dihydroxydiphenyl, $\lambda_{max.}$ 253, 292 mμ (log ε 4·09, 3·44); 3 : 4-dihydroxydiphenyl (Norris *et al., loc. cit.*), $\lambda_{max.}$ 267 mμ (log ε 4·12).

4-*Iodoveratrole.*—To stirred veratrole (13·8 g.) at 95° was added in small portions, during 20 min., an intimate mixture of iodine (30 g.) and mercuric oxide (14 g.), and the temperature was maintained at 95—100° for a further 30 min. The mixture was cooled and extracted with benzene, and the extract washed with sodium thiosulphate solution, then concentrated brine, and dried (Na_2SO_4). The solvent was removed and the residue distilled to give 4-iodoveratrole (18·8 g., 71%), b. p. 89—90°/0·2 mm., m. p. 34·5°. The brown residue from the distillation consisted mainly of 4 : 5-di-iodoveratrole.

1-(3 : 4-*Dimethoxyphenyl*)cyclo*hexanol* (V) *and* 2-cyclo*Hexylidene*cyclo*hexanone.*—To a vigorously stirred solution of phenyl-lithium, from lithium wire (0·8 g.), bromobenzene (9 g.), and ether (25 c.c.), at 0° was added, during 15 min., a solution of 4-iodoveratrole (13·2 g.) in ether (50 c.c.); a white precipitate was formed almost immediately. The suspension was stirred at 0° for a further 15 min. and at 20° for 1 hr., and was then cooled to 0° whilst a solution of *cyclo*hexanone (10 c.c.) in ether (30 c.c.) was added during 20 min.; the precipitate dissolved. After being stirred overnight at room temperature the mixture was cooled to 0° and decomposed by the dropwise addition of ice-cold water (75 c.c.), and the ethereal phase was washed with 5% aqueous sodium hydroxide, then with water, and dried (Na_2SO_4). Evaporation of the solvent left a light brown viscous oil which on distillation gave the fractions: (1) A fore-run of iodobenzene. (2) An oil (2·2 g.), b. p. 80—81°/0·3 mm., which solidified spontaneously and, crystallised (c), first, from light petroleum (b. p. 40—60°) and then from methanol, afforded 2-*cyclo*hexylidene*cyclo*hexanone (1·4 g.) as colourless needles, m. p. 55° (Reese, *Ber.*, 1942, **75**, 384, gives m. p. 57°) (Found: C, 80·8; H, 10·2. Calc. for $C_{12}H_{18}O$: C, 80·9; H, 10·1%) [semicarbazone, plates (from aqueous methanol), m. p. 180·5—181°, re-solidifying at 182·5°, and re-melting at 188·5—190° (Reese reports m. p.s 180° and 186—188°) (Found: N, 18·0. Calc. for $C_{13}H_{21}ON_3$: N, 17·9%)]. (3) An oil (5·6 g.), b. p. 136—142°/0·3 mm., which solidified spontaneously and on recrystallisation from light petroleum (b. p. 80—100°) afforded 1-(3 : 4-*dimethoxyphenyl*)cyclo*hexanol* (4·1 g., 35%), needles, m. p. 94·5° (Found: C, 71·5; H, 8·6. $C_{14}H_{20}O_3$ requires C, 71·2; H, 8·5%). 1-(2 : 3-Dimethoxyphenyl)-*cyclo*hexanol formed prisms, m. p. 50·5°.

1-(3 : 4-*Dimethoxyphenyl*)cyclo*hexene* (II).—A mixture of 1-(3 : 4-dimethoxyphenyl)*cyclo*hexanol (2·36 g.), anhydrous oxalic acid (0·4 g.), and dry toluene (15 c.c.) was refluxed, under an azeotropic water separator, until no further water was collected (30 min.). After cooling, the solution was filtered from oxalic acid, washed with water, dried (Na_2SO_4), and evaporated. Distillation of the residue gave a colourless oil (1·6 g., 74%), b. p. 120°/0·25 mm., which solidified spontaneously and on crystallisation (c) from light petroleum (b. p. 60—80°) afforded 1-(3 : 4-*dimethoxyphenyl*)cyclo*hexene* as needles, m. p. 58° (Found: C, 77·3; H, 8·2. $C_{14}H_{18}O_2$ requires C, 77·1; H, 8·3%). 1-(2 : 3-Dimethoxyphenyl)*cyclo*hexene had m. p. 15°.

2 : 3-*Dihydroxydiphenylmelanin.*—A rapid stream of oxygen was passed for 6½ hr. through a solution of 2 : 3-dihydroxydiphenyl (93 mg.) in a phosphate buffer (pH 8; 50 c.c.) at room temperature. The melanin was precipitated with hydrochloric acid, collected, and washed with water. After drying *in vacuo*, the brown amorphous product (39 mg.) had m. p. 110—140° (Found: C, 73·4; H, 4·1%).

2 : 3-*Diphenylbenzoquinone* (VII).—Silver oxide, prepared from silver nitrate (1 g.) as described by Willstätter and Müller (*Ber.*, 1908, **41**, 2581), and anhydrous sodium sulphate (2 g.) were suspended in dry ether (25 c.c.), and a solution of 2 : 3-dihydroxydiphenyl (186 mg.) in dry ether (25 c.c.) added all at once. After 15 minutes' shaking at room temperature the mixture was filtered and the deep red filtrate cooled to −75°; 2 : 3-*diphenylbenzoquinone* separated as a mixture of blades and prisms (114 mg., 62%), m. p. 92—94° (Found: C, 78·2; H, 4·6. $C_{18}H_{12}O_2$ requires C, 78·3; H, 4·4%). It was sparingly soluble in light petroleum, more soluble in ether, and readily soluble in benzene, dioxan, and alcohol. When hydrogenated at room temperature and atmospheric pressure in dioxan it absorbed 0·97 mol. of hydrogen. Light absorption: $\lambda_{max.}$ 241, 428 mμ (log ε 4·1, 3·5).

3 : 4-*Diphenylbenzoquinone* (VIII).—3 : 4-Dihydroxydiphenyl (Norris *et al., loc. cit.*) (186 mg.) was oxidised under the conditions used for the preceding preparation. 3 : 4-*Diphenylbenzoquinone* separated from its deep green ethereal solution as a mixture of spikes and blades (111 mg., 60%), m. p. 105·5—107·5° (Found: C, 78·4; H, 4·6%). The quinone had similar solubility

properties to those of 2 : 3-diphenylbenzoquinone. Light absorption : $\lambda_{max.}$ 251, 308, 405 mμ (log ε 4·0, 3·8, 3·4).

4-*Bromopyrogallol Trimethyl Ether.*—Bromine (160 g.) in dry carbon tetrachloride (500 c.c.) was added during 7 hr. to a vigorously stirred solution of pyrogallol trimethyl ether (168 g.) in dry carbon tetrachloride (500 c.c.), the temperature being kept at 4—5°. After the mixture had been kept overnight at room temperature the solvent was removed and the residual yellow oil distilled through a short Dufton column; the fraction with b. p. 95—105°/0·45 mm. was redistilled to give almost pure 4-bromopyrogallol trimethyl ether (203 g., 82%), b. p. 95—100°/0·2 mm. (Found : C, 43·9; H, 4·6; Br, 31·8. Calc. for $C_9H_{11}O_3Br$: C, 43·7; H, 4·5; Br, 32·4%). Upon nitration as described by Kohn and Grün (*loc. cit.*) this product afforded 4-bromo-5 : 6-dinitropyrogallol trimethyl ether, m. p. 137°, in 50% yield (Kohn and Grün, and Kohn and Gurewitsch, *locc. cit.*, report m. p. 134—135°) (Found : N, 8·0; Br, 23·5. Calc. for $C_9H_9O_7N_2Br$: N, 8·3; Br, 23·7%).

10-*Bromo*-11 : 12 : 13-*trimethoxydibenzo*[a, c]*phenazine.*—4-Bromo-5 : 6-dinitropyrogallol trimethyl ether (1·7 g.) in glacial acetic acid (50 c.c.) at 90° was reduced by the portion-wise addition of zinc dust (5 g.). After addition of further acetic acid (50 c.c.) the mixture was boiled for ½ min., and then rapidly filtered into a solution of 9 : 10-phenanthraquinone (0·75 g.) in glacial acetic acid (50 c.c.) at 80°. The solution was boiled for 2 min., diluted with cold water (5 c.c.), and allowed to cool. The yellow solid which separated was collected and twice recrystallised from glacial acetic acid, to give 10-*bromo*-11 : 12 : 13-*trimethoxydibenzo*[a, c]-*phenazine* (0·9 g.) as bright yellow felted needles, m. p. 219·5° (Found : C, 61·6; H, 4·0; N, 6·4; Br, 18·3. $C_{23}H_{17}O_3N_2Br$ requires C, 61·5; H, 3·8; N, 6·2; Br, 17·8%).

5-*Bromo*-6 : 7 : 8-*trimethoxy*-2 : 3-*diphenylquinoxaline.*—4-Bromo-5 : 6-dinitropyrogallol trimethyl ether (1·7 g.) was reduced and the diamine condensed with benzil (0·75 g.) in acetic acid under the conditions of the previous preparation. The acetic acid solution was diluted with hot water (100 c.c.) and cooled, and the solid was collected, dissolved in benzene–light petroleum (b. p. 60—80°), and chromatographed on alumina. The column was eluted with benzene, the eluate evaporated, and the residue was recrystallised from ethanol to yield the *quinoxaline* (0·6 g.) as very pale yellow needles, m. p. 159° (Found : C, 61·3; H, 4·2; N, 5·8; Br, 17·9. $C_{23}H_{19}O_3N_2Br$ requires C, 61·2; H, 4·2; N, 6·2; Br, 17·7%).

1-(2 : 3 : 4-*Trimethoxyphenyl*)cyclo*hexanol* (VI).—To a stirred solution of phenyl-lithium, from lithium wire (6·4 g.) and bromobenzene (69 g.) in ether (200 c.c.), was added at 0° during 30 min. 4-bromopyrogallol trimethyl ether (99 g.) in ether (200 c.c.). Treatment with *cyclo*hexanone (53 c.c.) in ether (100 c.c.) and working up as for (V) gave a fraction, b. p. 123—128°/0·1 mm., which, crystallised from light petroleum (b. p. 40—60°), afforded 1-(2 : 3 : 4-trimethoxyphenyl)*cyclo*hexanol, rhombic platelets (36 g., 34%), m. p. 65° (Ginsburg and Pappo, *loc. cit.*, report m. p. 66—67°) (Found : C, 68·1; H, 8·5. Calc. for $C_{15}H_{22}O_4$: C, 67·7; H, 8·3%). From a later preparation, thick needles, m. p. 79·5°, were obtained (Found : C, 67·6; H, 8·5 %).

1-(2 : 3 : 4-*Trimethoxyphenyl*)cyclo*hexene* (III).—1-(2 : 3 : 4-Trimethoxyphenyl)*cyclo*hexanol (22·5 g., m. p. 79·5°), anhydrous oxalic acid (4·5 g.) and dry toluene (200 c.c.), caused to react and worked up as for (II), gave an oil (19·8 g., 95%), b. p. 123—124°/0·2 mm., which solidified and crystallised (c) from light petroleum (b. p. 40—60°), affording the *cyclo*hexene (III) as hexagonal platelets, m. p. 40°, undepressed upon admixture with material similarly prepared from the low-melting form of the *tert.*-alcohol (Ginsburg and Pappo, *loc. cit.*, report this *cyclo*hex-1-ene as an oil) (Found : C, 72·6; H, 8·4. Calc. for $C_{15}H_{20}O_3$: C, 72·6; H, 8·1%).

2 : 3 : 4-*Trimethoxydiphenyl.*—1-(2 : 3 : 4-Trimethoxyphenyl)*cyclo*hexene (14·8 g.) in xylene (130 c.c.) was dehydrogenated with chloranil (29·3 g.) as described for 2 : 3-dimethoxydiphenyl. Distillation of the crude product afforded a viscous red oil, b. p. 121—122°/0·1 mm., from which, by crystallisation (c) from light petroleum (b. p. 40—60°), 2 : 3 : 4-*trimethoxydiphenyl* (12·3 g., 85%) was obtained as colourless needles, m. p. 46·5° (Found : C, 73·6; H, 6·7. $C_{15}H_{16}O_3$ requires C, 73·8; H, 6·6%).

2 : 3 : 4-*Trihydroxydiphenyl.*—Demethylation of 2 : 3 : 4-trimethoxydiphenyl (10·6 g.) in chlorobenzene (110 c.c.) was effected with aluminium chloride (17·5 g.) as described for 2 : 3-dihydroxydiphenyl. The solid remaining after removal of the solvent was washed with cold benzene and sublimed at 165°/0·05 mm., the sublimate (7·8 g., 89%), on crystallisation from xylene under nitrogen, affording 2 : 3 : 4-*trihydroxydiphenyl* as colourless blades, m. p. 216° (Found : C, 71·2; H, 4·9. $C_{12}H_{10}O_3$ requires C, 71·3; H, 5·0%). The *triacetate* crystallised from benzene–light petroleum (b. p. 60—80°) in hexagonal plates, m. p. 111° (Found : C, 65·8; H, 4·8; Ac, 40·3. $C_{18}H_{16}O_6$ requires C, 65·9; H, 4·9; Ac, 39·3%).

Diphenylpurpurogallin (XI).—(*a*) 2 : 3 : 4-Trihydroxydiphenyl (0·5 g.) was dissolved in a

mixture of dioxan (7·5 c.c.) and water (5 c.c.) at 0° and an ice-cold solution of sodium iodate (0·274 g. of $NaIO_3,H_2O$) in water (5 c.c.) added dropwise. The mixture was shaken for 10 min., water (10 c.c.) added, and shaking continued at room temperature for a further 20 min. The dark, granular solid was collected, washed with water, and dried *in vacuo*. Sublimation at 190°/6 × 10^{-4} mm. yielded a powder, which upon crystallisation from benzene–light petroleum (b. p. 60—80°) afforded ***diphenylpurpurogallin*** as golden-orange felted needles (59 mg., 13%), m. p. 211° (Found: C, 73·9; H, 4·4. $C_{22}H_{16}O_5$ requires C, 74·2; H, 4·3%). Light absorption: $\lambda_{max.}$ 223, 290, 325, 362, 445 mμ (log ε 4·26, 4·41, 4·66, 3·83, 3·64).

(*b*) 2 : 3 : 4-Trihydroxydiphenyl (100 mg.) in dioxan (5 c.c.) was added to a solution of sodium hydrogen carbonate (5 mg.; "AnalaR") in water (10 c.c.) at room temperature, and a stream of small bubbles of oxygen passed through the mixture. After 12 hr. the diphenylpurpurogallin was collected. It consisted of brick-red needles (63 mg., 68%), m. p.s 117° and 209—210°. Similar results were obtained when disodium hydrogen phosphate was used instead of sodium hydrogen carbonate.

Dimethylpurpurogallin (X).—A solution of 2 : 3 : 4-trihydroxytoluene (140 mg.) and sodium hydrogen carbonate (10 mg.) in a mixture of water (16 c.c.) and dioxan (4 c.c.) was oxygenated at room temperature for 4 hr. Dimethylpurpurogallin separated as orange needles (62 mg., 50%), m. p. 201—202°, undepressed upon admixture with material prepared by iodate oxidation of 2 : 3 : 4-trihydroxytoluene. Recrystallised from toluene, dimethylpurpurogallin formed felted orange needles, m. p. 203° (Critchlow *et al.*, *loc. cit.*, give m. p. 185°) (Found: C, 62·9; H, 4·5. Calc. for $C_{13}H_{12}O_5$: C, 62·9; H, 4·8%). Light absorption: $\lambda_{max.}$ 230, 245, 285, 309, 366, 388, 440 mμ (log ε 4·00, 4·09, 4·41, 4·52, 3·66, 3·72, 3·51).

Purpurogallin (IX).—This compound, prepared by the method of Dehn and Evans (*J. Amer. Chem. Soc.*, 1930, **52**, 3647) and Haworth, Moore, and Pauson (*J.*, 1948, 1045), was purified by sublimation at 230°/0·1 mm. followed by crystallisation from xylene, from which it separated as deep orange-red needles, m. p. 280° (decomp.). Light absorption: $\lambda_{max.}$ 230, 246, 281, 305, 359, 376, 420 mμ (log ε 4·10, 4·15, 4·38, 4·49, 3·73, 3·71, 3·50).

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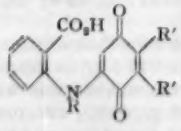
The Reaction between Quinones and Anthranilic Acids.

By R. M. ACHESON and B. F. SANSOM.

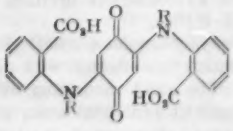
[Reprint Order No. 6626.]

Quinone reacted with two mols. of anthranilic acid and its derivatives to give the corresponding 2 : 5-dianilinoquinones, some of which were cyclised by sulphuric acid. Monoanilinoquinones were not isolable from these reactions but one was obtained from 2 : 3-dimethoxyquinone.

DESCRIPTIONS of the reactions between anthranilic acid and benzoquinone (Ville and Astre, *Bull. Soc. chim. France*, 1895, **13**, 746; Astre, *ibid.*, 1896, **15**, 1025) and toluquinone (Suchanek, *J. prakt. Chem.*, 1914, **90**, 467), and of these quinones with *N*-ethylanthranilic acid (Linke, *ibid.*, 1920, **101**, 265) suggest that mono- and di-addition compounds (I and II; R = R′ = H) are formed under similar conditions, the quinol formed initially being oxidised by excess of quinone. The dimethoxy- and dihydroxy-derivatives of the quinone



(I)



(II)

(II; R = H) but no monoaddition products are reported as obtained (Lewicka, *Roczniki Chem.*, 1926, **6**, 881) from 2-amino-5-methoxy- and 2-amino-5-hydroxy-benzoic acid and benzoquinone. Compounds of type (I) have also been prepared from 1 : 4-naphthaquinone and anthranilic acid (Lesnianski, *Ber.*, 1918, **51**, 695; cf. Hauschka, *J. prakt. Chem.*,

1914, **90**, 447; Yakushevskii, *J. Gen. Chem. U.S.S.R.*, 1939, **9**, 1877; *Chem. Abs.*, 1940, **34**, 4070) and 2-amino-5-methoxybenzoic acid (Lewicka, *loc. cit.*), and the products have been cyclised to acridones with sulphuric acid.

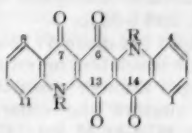
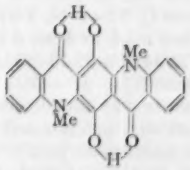
Cyclisation of the benzoquinone (I; R = R′ = H), preceded or followed by reduction, appeared to offer an interesting route to hydroxyacridone derivatives. According to the earlier papers the compounds mentioned were little purified black solids with fairly high decomposition points. No derivatives were prepared, and identifications were often based only on poor analytical data, which did not differentiate, for example, between the two possible products from *p*-benzoquinone and anthranilic acid.

The only product we were able to obtain from anthranilic acid and a large excess of benzoquinone in boiling ethanol was 2 : 5-di-(*o*-carboxyanilino)-*p*-benzoquinone (II; R = H) (contrast Ville and Astre, *loc. cit.*). This crystallised from *m*-cresol and gave the dimethyl ester with diazomethane, also obtained directly from the quinone and methyl anthranilate. Reduction of the quinone (II; R = H) by sodium dithionite gave the quinol which was slowly oxidised to the quinone by air.

p-Benzoquinone and *N*-methylanthranilic acid similarly gave the diaddition product (II; R = Me) (characterised as the methyl ester), but *N*-ethylanthranilic acid did not give a crystalline product (contrast Linke, *loc. cit.*), nor did toluquinone with anthranilic acid (contrast Suchanek, *loc. cit.*).

2 : 3-Dimethoxy-*p*-benzoquinone combined with anthranilic acid, but not with its methyl ester or *N*-methyl derivative, to give 5-(*o*-carboxyanilino)-2 : 3-dimethoxy-*p*-benzoquinone (I; R = H, R′ = OMe). The hydroxyl groups of the quinol, obtained on catalytic reduction, did not react with diazomethane and the product was the quinone ester because of aerial oxidation. Reductive methylation of the quinone gave a black tar containing a trace of 2′ : 3′ : 4′ : 5′-tetramethoxydiphenylamine-2-carboxylic acid.

Treatment of the quinone (II; R = H) with concentrated sulphuric acid at 150—180° gave a dark brown product, which was insoluble in all solvents examined except concentrated sulphuric acid; it could not be obtained analytically pure. As it did not dissolve in dilute aqueous sodium hydroxide it is probably largely 5 : 6 : 7 : 12 : 13 : 14-hexahydro-6 : 7 : 13 : 14-tetraoxo-5 : 12-diazapentacene (III; R = H), in agreement with Scharwin, Bonderewski and Januschewski (*J. Russ. Phys. Chem. Soc.*, 1915, **47**, 1260; *Chem. Zentr.*, 1916, II, 16) and not 2-(*N*-*o*-carboxyanilino)-1 : 4 : 5 : 10-tetrahydro-1 : 4 : 5-trioxoacridine as claimed by Suchanek (*loc. cit.*).

(III)  (IV) 

Similar cyclisation of the *N*-methyl-quinone (II; R = Me) gave the diazapentacene (III; R = Me) which on reduction gave a blue quinol (IV). This formulation is supported by infrared absorption data: the quinone (III; R = Me) shows a maximum at 5·96 μ, similar to that shown by anthraquinone (5·97 μ; Flett, *J.*, 1948, 1441), corresponding to the 6 : 13-carbonyl groups and there is no evidence of hydroxyl groups or hydrogen bonding. This peak is absent in the quinol (IV) but a new maximum, at 3·75 μ, indicates the presence of a hydrogen-bonded hydroxyl group; there is no maximum at *ca.* 3·0 μ which would be expected from an ordinary phenolic hydroxyl group in this type of compound. These results are in agreement with the infrared absorption spectra of the four 1 : 2 : 3 : 4-monohydroxy-trimethoxy-10-methylacridones (Crow and Price, *Austral. J. Sci. Res.*, 1949, *A*, **2**, 282): the quinone (III; R = Me) and 10-methylacridone (Acheson, Burstall, Jefford, and Sansom, *J.*, 1954, 3742) showed sharp maxima at 6·17 and 6·23 μ, and 6·13 and 6·26 μ, respectively, the first of each pair corresponding to the acridone-carbonyl group, while there is a single much broader maximum at 6·26 μ (with a shoulder at 6·22 μ) in the case of the quinol (IV) which confirms the postulate of hydrogen bonding.

Experimental

2 : 5-*Di*-(o-*carboxyanilino*)-p-*benzoquinone* (II; R = H).—Anthranilic acid (7·0 g.) and *p*-benzoquinone (freshly steam-distilled; 8·0 g.) in ethanol (75 ml.) were heated at 50—55° for 6 hr. After 3 days at room temperature a black solid (7·1 g.) was collected from the red-black mixture and washed with water and ethanol. Recrystallisation from *m*-cresol gave the *aminobenzoquinone* (II; R = H) as an orange microcrystalline powder, m. p. 335° (decomp.) (Found: C, 63·1; H, 4·0; N, 6·9. $C_{20}H_{14}O_6N_2$ requires C, 63·5; H, 3·7; N, 7·4%).

2 : 5-*Di*-(o-*methoxycarbonylanilino*)-p-*benzoquinone* was obtained from the acid with ethereal diazomethane and separated from pentyl alcohol in red needles, m. p. 265—267° (Found: C, 65·5; H, 4·7; N, 6·9. $C_{22}H_{18}O_6N_2$ requires C, 65·0; H, 4·4; N, 6·9%). The same ester (2·0 g.), m. p. and mixed m. p. 265—267°, separated on cooling a mixture of methyl anthranilate (4·0 g.), *p*-benzoquinone (4·0 g.), and ethanol (50 ml.) which had been refluxed for 5 hr.

2 : 5-*Di*-(o-*carboxyanilino*)*quinol* was precipitated when a solution of the corresponding quinone in aqueous sodium hydroxide was decolourised with sodium dithionite (hydrosulphite) and acidified. It separated from ethanol in colourless needles, m. p. *ca.* 300° (decomp.) (Found: C, 63·0; H, 4·1; N, 7·3. $C_{20}H_{16}O_6N_2$ requires C, 63·2; H, 4·2; N, 7·4%). It was oxidised by air to the quinone slowly at room temperature and rapidly at 100°.

2 : 5-*Di*-(o-*carboxy*-N-*methylanilino*)-p-*benzoquinone* (II; R = Me).—*N*-Methylanthranilic acid (6·0 g.) and *p*-benzoquinone (6·5 g.) were refluxed in ethanol (50 ml.) for 6 hr. The *aminobenzoquinone* (2·7 g.) was collected from the deep red solution and separated from ethanol in red rhombs, m. p. 260° (decomp.) (Found: C, 65·1; H, 4·3; N, 6·7. $C_{22}H_{18}O_6N_2$ requires C, 65·0; H, 4·4; N, 6·9%). The *dimethyl ester*, prepared with diazomethane in methanol–ether, separated from ethanol in red needles, m p 225° (Found: C, 66·8; H, 5·4; N, 6·1 $C_{24}H_{22}O_6N_2$ requires C, 66·4; H, 5·1; N, 6·5%) Refluxing *p*-benzoquinone (2 g.) and methyl *N*-methylanthranilate (2 g.) in ethanol (50 ml.) gave a deep red solution from which none of the quinone ester could be isolated. Evaporation gave only *p*-benzoquinone and a black tar.

2 : 5-*Di*-(o-*carboxy*-N-*methylanilino*)*quinol*, obtained as above, separated from ethanol in colourless rhombs, decomp. *ca.* 300° (Found: C, 65·0; H, 5·3; N, 6·4. $C_{22}H_{20}O_6N_2$ requires C, 64·7; H, 4·9; N, 6·9%); it was oxidised rapidly to the quinone above 200°.

5 : 6 : 7 : 12 : 13 : 14-*Hexahydro*-5 : 12-*dimethyl*-6 : 7 : 13 : 14-*tetraoxo*-5 : 12-*diazapentacene* (III; R = Me).—2 : 5-Di-(o-carboxy-*N*-methylanilino)-*p*-benzoquinone (0·1 g.) was heated with concentrated sulphuric acid (2 ml.) for 2 hr. at 170—180° and then poured into boiling water. The precipitated *diazapentacene* was washed with water and dried. It was easily soluble in *m*-cresol, pentyl alcohol, and acetic acid, sparingly so in ethanol and ethyl acetate, and separated from butanol as a yellow microcrystalline powder, m. p. 342° (Found: C, 71·6; H, 3·8; N, 7·5. $C_{22}H_{14}O_4N_2$ requires C, 71·4; H, 3·8; N, 7·6%). Its infrared absorption spectrum (3·7—7 μ) in paraffin paste had max. at 5·96, 6·17, 6·23, 6·54, 6·72, and 6·83 μ.

5 : 7 : 12 : 14-*Tetrahydro*-6 : 13-*dihydroxy*-5 : 12-*dimethyl*-7 : 14-*dioxo*-5 : 12-*diazapentacene* (IV).—The above quinone (III; R = Me) (0·05 g.) gave a yellow solution in hot acetic acid (10 ml.), and sodium dithionite was added until the colour changed through green to royal blue. The *dihydroxydiazapentacene*, precipitated by pouring the mixture into water, crystallised from acetic acid in blue needles, m. p. 260° (Found: C, 70·4; H, 4·4; N, 7·4. $C_{22}H_{16}O_4N_2$ requires C, 71·0; H, 4·3; N, 7·5%); infrared absorption max. (paraffin paste) were at 3·75, 6·26 (shoulder at 6·2), 6·40, 6·66, and 6·83 μ.

2 : 3-*Dimethoxyquinone*.—This was prepared according to Baker (*J.*, 1931, 2542) with the following modifications. 3 : 4-Dimethoxysalicylic acid (122 g.; m. p. not less than 167°; less pure material gave low yields at the nitration stage) was heated under reflux at atmospheric pressure for 1 hr. Distillation gave 2 : 3-dimethoxyphenol (82 g.), b. p. 236—242° (on redistillation). 2 : 3 : 4-Trimethoxynitrobenzene was hydrogenated in methanol at room temperature and pressure over Raney nickel. Filtration into methanolic hydrogen chloride followed by evaporation gave 2 : 3 : 4-trimethoxyaniline hydrochloride quantitatively. 2 : 3-Dimethoxyquinone was characterised as its *mono*-2 : 4-*dinitrophenylhydrazone*, which separated from ethyl acetate in orange needles, m. p. 196° (Found: C, 48·4; H, 3·5. $C_{14}H_{12}O_7N_4$ requires C, 48·2; H, 3·4%).

2-(o-*Carboxyanilino*)-5 : 6-*dimethoxy*-p-*benzoquinone* (I; R = H, R′ = OMe).—2 : 3-Dimethoxybenzoquinone (2·4 g.) and anthranilic acid (1·22 g.) were refluxed in methanol (50 ml.; lower yields were obtained by using ethanol or propanol) for 66 hr., and about half the solvent was evaporated. The red-black solution was cooled at 0° for 24 hr., and the precipitate collected, washed with a little methanol, and dried (1·34 g.). Recrystallisation by cooling a boiling

saturated methanol solution to −70° gave a 92% recovery of the quinone as dark orange-red needles, m. p. 217—218° (Found: C, 59·2; H, 4·5; N, 4·8. $C_{15}H_{13}O_6N$ requires C, 59·4; H, 4·3; N, 4·6%). Treatment in methanol with ethereal diazomethane gave the *methyl ester*, which separated from acetone in red needles, m. p. 124—125° (Found: C, 60·3; H, 4·8. $C_{16}H_{15}O_6N$ requires C, 60·6; H, 4·7%).

.The deep red solution of the carboxyanilinoquinone (0·19 g.) in methanol or ether became pale yellow when one mol. of hydrogen had been absorbed at room temperature and pressure over Raney nickel. Filtration into excess of ethereal diazomethane followed by evaporation after 12 hr., during which the solution reddened greatly, gave only the methoxycarbonylanilinoquinone (0·1 g.) and a deep red gum.

The quinone (I; R = H, R′ = OMe) (0·29 g.) was dissolved in sodium hydroxide (0·56 g.) and water (3 ml.), and dithionite was added until the deep purple solution changed through red to yellow. Methyl sulphate (0·33 g.) was added and the mixture refluxed. Sodium dithionate was added occasionally to keep the solution yellow and refluxing continued (2 hr.) until a drop of the solution did not clearly redden in air. Acidification of the brown solution precipitated a black tar which was purified through aqueous potassium hydrogen carbonate (charcoal). Recrystallisation of the benzene-soluble fraction from benzene–light petroleum (b. p. 60—80°) gave <1 mg. of pale yellow needles, m. p. 157°. Hughes, Neill, and Ritchie (*Austral. J. Sci. Res.*, 1950, *A*, **2**, 282) report m. p. 159—160° for 2′ : 3′ : 4′ : 5′-tetramethoxydiphenylamine-2-carboxylic acid.

We thank Mr. A. O. Plunkett for technical assistance and Mr. F. Hastings for the spectral data which were obtained under the supervision of Dr. F. B. Strauss.

The Laboratory of Human Nutrition, Department of Biochemistry.
Dyson Perrins Laboratory, Oxford. [*Received, July 18th*, 1955.]

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*A Novel Reaction of Thiourea, the Structure of Jaffé's Base, and Related Studies.**

By B. H. Chase and James Walker.

[Reprint Order No. 6615.]

Condensation of α-bromo-*p*-chlorophenylacetonitrile with thiourea in acetone solution gave, besides the expected 2 : 4-diamino-5-*p*-chlorophenylthiazole (I; R = Cl), the dihydrobromide of a base $C_5H_{10}N_4S$, shown to be 2 : 6-diamino-4 : 4-dimethyl-1 : 3 : 5-thiadiazine (II) by synthesis of the dihydrobromide from thiodiformamidine dihydrobromide (III) and acetone. This recalled the formation of Jaffé's base, $C_6H_{10}N_4S$, hitherto formulated as a substituted thiodiformamidine (V), on treating ethylenethiourea (IV) with 5 : 5-dibromohydroxyhydrouracil. Jaffé's base, however, is monoacidic, and cannot have the dihydroglyoxalinyl sulphide structure (V); it appears to be 4 : 5-dihydro-1-(4 : 5-dihydroglyoxalin-2-yl)-2-mercaptoglyoxaline (as X), a conclusion supported by a comparison of its ultraviolet absorption spectrum with that of amidinothiourea (XI).

Various heterocyclic compounds derived from acetone by reaction with thiourea–hydrobromic acid, amidinothiourea, and *S*-methyl*iso*thiourea are mentioned, and a refinement of the Grote colour test for certain types of sulphur compounds is described.

In continuation of our study of aryl-substituted heterocyclic diamines as potential chemotherapeutic agents (Chase, Thurston, and Walker, *J.*, 1951, 3439; Thurston and Walker, *J.*, 1952, 4542; Chase and Walker, *J.*, 1953, 3518, 3548; B.P. 717,250), we have had occasion to prepare 2 : 4-diamino-5-phenyl- (I; R = H) and -5-*p*-chlorophenyl-thiazole (I; R = Cl). Condensation between α-chloro-α-phenylacetonitrile and thiourea in acetone

* Based on a communication presented at the XIVth International Congress of Pure and Applied Chemistry, Zürich, July, 1955.

solution * at room temperature gave the hydrochloride of 2 : 4-diamino-5-phenylthiazole (I; R = H) in good yield although similar condensation using α-bromo-α-phenylacetonitrile was less satisfactory. When the condensation of α-bromo-*p*-chlorophenylacetonitrile with thiourea was carried out in acetone solution in the cold there was formed, however, in moderate yield, in addition to the expected hydrobromide of 2 : 4-diamino-5-*p*-chlorophenylthiazole (I; R = Cl), the dihydrobromide of a base $C_5H_{10}N_4S$, ostensibly derived from one molecular proportion of acetone and two of thiourea. As the base $C_5H_{10}N_4S$ gave a dihydrobromide it obviously contained two isolated basic centres and the only likely structure was that of 2 : 6-diamino-4 : 4-dimethyl-1 : 3 : 5-thiadiazine (II); confirmation of this structure came when the dihydrobromide was subsequently obtained synthetically by condensation of thiodiformamidine dihydrobromide (III) with acetone.

$$Br\{NH_2{\cdot}C(\cdot NH_2){\cdot}S{\cdot}C(\cdot NH_2){:}NH_2\}Br \quad \text{(III)}$$

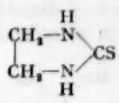
The formation of the thiadiazine dihydrobromide, from acetone and thiourea in the presence of α-bromo-*p*-chlorophenylacetonitrile, recalled the production of a base, $C_6H_{10}N_4S$, by the oxidation of ethylenethiourea (IV) with 5 : 5-dibromohydroxyhydrouracil (in effect, hypobromous acid) (Johnson and Edens, *J. Amer. Chem. Soc.*, 1941, **63**, 1058), which proved to be identical with Jaffé's base, obtained originally by the action of thiocarbonyl chloride on ethylenediamine (Jaffé and Kühn, *Ber.*, 1894, **27**, 1664). In view of its formation by direct oxidation of ethylenethiourea (IV), Johnson and Edens (*loc. cit.*) preferred the dihydroglyoxalinyl sulphide structure (V) for Jaffé's base, a formulation which Jaffé had considered but had discarded in favour of (VI) (Jaffé and Kühn, *loc. cit.*). Johnson and Edens (*J. Amer. Chem. Soc.*, 1942, **64**, 2706) later obtained Jaffé's base by oxidising ethylenethiourea (IV) with iodine to the disulphide (VII), and allowing the hydroperiodide † of the latter to decompose in boiling aqueous solution. Moreover, the hydrochloride (m. p. 270°; Jaffé and Kühn, *loc. cit.*) of Jaffé's base was almost certainly the unidentified substance, "$C_6H_{11}N_4ClS$," m. p. 270°, isolated by Rây and Das (*J.*, 1922, **121**, 323) from the reaction of ethylenethiourea with chloropicrin. Jaffé's base, however, is monoacidic, and, as one would expect the substituted thiodiformamidine structure (V), like thiodiformamidine itself and 2 : 6-diamino-4 : 4-dimethyl-1 : 3 : 5-thiadiazine (II), to be diacidic, we were led to doubt the structure assigned to Jaffé's base by Jaffé and Kühn and by Johnson and Edens (*locc. cit.*). Recently, however, Lecher and Gubernator (*J. Amer. Chem. Soc.*, 1953, **75**, 1087) have shown that the disulphide (VIII) obtained from *NNN'*-trimethylthiourea is unstable in acid aqueous media and decomposes on boiling under these conditions to give sulphur and *N*-(trimethylamidino)-*NN'N'*-trimethylthiourea (IX), as a monoacidic base, together with other decomposition products; they were led by this observation, and its similarity to Johnson and Edens's later method for its preparation from the disulphide (VII), to suggest that Jaffé's base has the structure (X), rather than that (V) advocated by Johnson and Edens (*loc. cit.*), and our observations, recorded below, support thi sview. The substance "$C_4H_{11}N_4ClS$" ($C_4H_{10}N_4S,HCl$) obtained from methylthiourea and chloropicrin (Rây and Das, *loc. cit.*) is presumably also to be formulated as a derivative of amidinothiourea.

Reverting to 2 : 6-diamino-4 : 4-dimethyl-1 : 3 : 5-thiadiazine dihydrobromide (cf. II), one may ascribe its formation from thiourea in acetone solution in the presence of α-bromo-*p*-chlorophenylacetonitrile to decomposition of the intermediate *S*-(*p*-chloro-α-cyanobenzyl)*iso*thiourea, $CH(C_6H_4Cl)(CN){\cdot}S{\cdot}C(:NH){\cdot}NH_2$, to give cyanamide, which reacts with unchanged thiourea in the presence of hydrogen bromide (from hydrolysis of the thiuronium

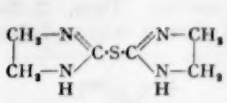
* It may be noted that Miller, Sprague, Kissinger, and McBurney (*J. Amer. Chem. Soc.*, 1940, **62**, 2099) found that the reaction between chloroacetonitrile and thiourea in acetone solution in the cold only proceeded as far as *S*-(cyanomethyl)thiuronium chloride, $CH_2(CN){\cdot}S{\cdot}C(\cdot NH_2){:}NH_2Cl$, which underwent ring-closure to 2 : 4-diaminothiazole hydrochloride in warm alcohol (Land, Ziegler, and Sprague, *J. Org. Chem.*, 1946, **11**, 622), the latter product being obtained directly when the reaction is carried out in cold methanol (Davies, Maclaren, and Wilkinson, *J.*, 1950, 3491) or hot ethanol (Davies *et al.*, *loc. cit.*; Zerweck and Schubert, G.P. 729,853).

† Johnson and Edens (*loc. cit.*) formulated this hydroperiodide as $C_6H_{10}N_4S_2,HI,2I_2$, implying that the disulphide (VII) is monoacidic; the hydroperiodide, however, is more probably $C_6H_{10}N_4S_2,2HI,I_2$, and the analysis of the dihydrochloride of (VII) (Freedman and Corwin, *J. Biol. Chem.*, 1949, **181**, 617) definitely shows that (VII) is, as one would expect, a diacidic base.

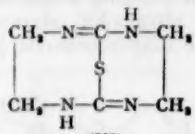
bromide) to give thiodiformamidine dihydrobromide (III), and the latter on condensation with acetone gives 2 : 6-diamino-4 : 4-dimethyl-1 : 3 : 5-thiadiazine dihydrobromide. Indeed, reaction between cyanamide and thiourea in the presence of alcoholic hydrogen chloride, or bromide, was found to take place exothermally with great ease (cf. Chabrier, Renard, and Renier, *Compt. rend.*, 1952, **235**, 64) to give thiodiformamidine dihydrochloride, or dihydrobromide (III), and subsequent reaction of (III) with acetone afforded the dihydrobromide of 2 : 6-diamino-4 : 4-dimethyl-1 : 3 : 5-thiadiazine (II) in moderate



(IV)

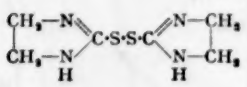


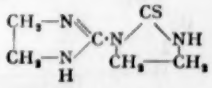
(V)



(VI)

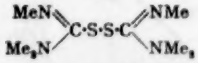
(VII)

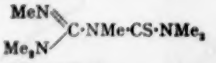




(X)

(VIII)





(IX)

yield. Alternatively,* the "positive" bromine in α-bromo-*p*-chlorophenylacetonitrile might have caused intermediate formation of dithiodiformamidine dihydrobromide, $Br\{NH_2{\cdot}C(:NH_2){\cdot}S{\cdot}S{\cdot}C(:NH_2){\cdot}NH_2\}Br$, which could decompose to give cyanamide, sulphur, thiourea, and hydrogen bromide (cf. Claus, *Annalen*, 1875, **179**, 142; McGowan, *J.*, 1886, **49**, 192), leading, by the reaction just discussed, to thiodiformamidine dihydrobromide (III), and thence to the dihydrobromide of 2 : 6-diamino-4 : 4-dimethyl-1 : 3 : 5-thiadiazine (II); on the other hand, if dithiodiformamidine were to decompose in accordance with the analogy of Lecher and Gubernator's disulphide (VIII), the product would be amidinothiourea (XI), and this was shown to react with acetone (in the presence of piper-

$$NH_2{\cdot}C(:NH){\cdot}NH{\cdot}CS{\cdot}NH_2 \quad (XI)$$

idine) to give 4-amino-1 : 2-dihydro-6-mercapto-2 : 2-dimethyl-1 : 3 : 5-triazine (as XII), since the latter (XII) was also obtained by demethylation of 4-amino-1 : 2-dihydro-2 : 2-dimethyl-6-methylthio-1 : 3 : 5-triazine (XIII) by the method of Fairfull, Lowe, and Peak (*J.*, 1952, 743). The conditions for the condensation of thiodiformamidine with acetone were not studied in detail, but considerations relating to the condensation of *p*-chlorophenyldiguanide with acetone (Carrington, Crowther, and Stacey, *J.*, 1954, 1017) are doubtless applicable; as in the case of the latter reaction, no condensation occurred between free thiodiformamidine base and acetone.

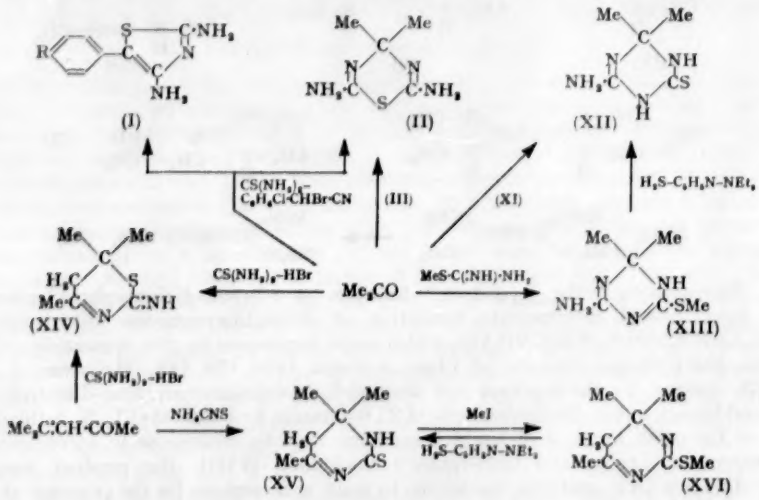
Direct reaction between thiourea and acetone in the presence of hydrobromic acid gave, in small yield, a base $C_7H_{12}N_2S$, characterised as the picrate, and the same substance was obtained more readily from mesityl oxide, thiourea, and concentrated aqueous hydrobromic acid. The substance, forming a picrate, was obviously 2-amino-4 : 6 : 6-trimethyl-1 : 3-thiazine, or a tautomeric form † (XIV), and the picrate was probably identical with the "thiocarbamide-acetone picrate, $C_{10}H_{13}O_8N_5S$" isolated by Taylor (*J.*, 1922, **121**, 2271) after allowing acetone and thiourea to react in the presence of hydrogen chloride, phosphoryl

* Johnson has reported (*J. Amer. Chem. Soc.*, 1940, **62**, 2269) that 5 : 5-dibromohydroxyhydrouracil and thiourea react in water or alcohol to give 5-bromouracil (quantitatively), free sulphur, cyanamide, and hydrobromic acid.

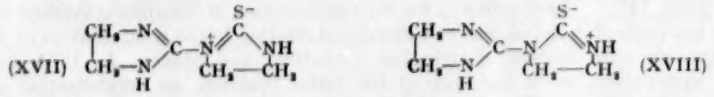
† A number of substances described in this communication are capable of existing in tautomeric modifications. As the nature of this possible tautomerism is obvious, and not particularly relevant to the main theme, no special mention is made of it. For the sake of convenience, however, (XII) and (XV) are named as dihydromercapto-compounds, rather than tetrahydrothioxo-compounds, although ultraviolet absorption characteristics and colour reactions indicate that the substances contain >C:S rather than >C·SH groups.

chloride, or phosphorus trichloride. The base (XIV) is isomeric with the non-basic 4 : 5-dihydro-2-mercapto-4 : 4 : 6-trimethylpyrimidine (XV), obtained from mesityl oxide and ammonium thiocyanate in boiling toluene; the substance (XV) must have the sulphur atom in the extracyclic position to account for its lack of conventional basicity, and also since it could be methylated to the methylthio-derivative, 4 : 5-dihydro-4 : 4 : 6-trimethyl-2-methylthiopyrimidine (XVI), and regenerated from the latter on demethylation by the method of Fairfull, Lowe, and Peak (*loc. cit.*).

Further evidence concerning the structures of the above substances came from a study of their ultraviolet absorption spectra. Thus, 2 : 6-diamino-4 : 4-dimethyl-1 : 3 : 5-thiadiazine dihydrobromide (cf. II) showed only end-absorption in N-hydrochloric acid,



as did thiodiformamidine dihydrobromide (III) (Fig. 1). In methanol, however, the former salt showed a distinct shoulder at ~240 mμ, while the latter, being more extensively hydrolysed, showed an intense band at 242 mμ. The ultraviolet absorption spectrum of Jaffé's base in methanol (Fig. 2) showed two intense bands, thus excluding the substituted



thiodiformamidine (dihydroglyoxalinyl sulphide) structure (V) or, indeed, a symmetrical structure for this substance, and, in terms of structure (X) for Jaffé's base, the two distinct polar excited states giving rise to the two bands may be written as (XVII) and (XVIII). The correctness of structure (X) for Jaffé's base is strongly supported by the similarity between the ultraviolet absorption spectrum in methanol of that substance and that of amidinothiourea (XI), in which the two bands are displaced to slightly lower frequencies. The ultraviolet absorption spectrum of Jaffé's base (X) was scarcely altered in N-hydrochloric acid but the absorption band at higher frequency in that of amidinothiourea (XI) was suppressed under these conditions, although it was present at reduced intensity in the spectrum of amidinothiourea hydrochloride in methanol (Fig. 2). The two remaining unsymmetrical structures containing the $>C{:}S$ group, 4-amino-1 : 2-dihydro-6-mercapto-2 : 2-dimethyl-1 : 3 : 5-triazine (XII) and 4 : 5-dihydro-2-mercapto-4 : 4 : 6-trimethylpyrimidine (XV), had ultraviolet absorption spectra suggesting fusion of two bands of equal intensity into one broad band in the case of the latter and fusion of two bands of nearly equal intensity into one band with a shoulder in the case of the former.

The colour reactions given by the above substances with Grote's reagent (*J. Biol. Chem.*, 1931, **93**, 25) also classified Jaffé's base as a substance containing a $>C{:}S$ grouping. Thus, thiourea, ethylenethiourea (IV), Jaffé's base (X), amidinothiourea (XI), 4-amino-1 : 2-dihydro-6-mercapto-2 : 2-dimethyl-1 : 3 : 5-triazine (XII), and 4 : 5-dihydro-2-mercapto-4 : 4 : 6-trimethylpyrimidine (XV) gave green, blue-green, or blue colours with Grote's reagent, as did the following substances examined in studying the scope of the reaction : monomethylthiourea, *NN'*-dimethylthiourea, *p*-chlorophenylamidino)thiourea, 6-methyl-2-thiouracil, 1 : 4 : 6-trimethyl-2-thiopyrimidone, and 6-methyl-4-thiopyrimidone (cf.

FIG. 1. FIG. 2.

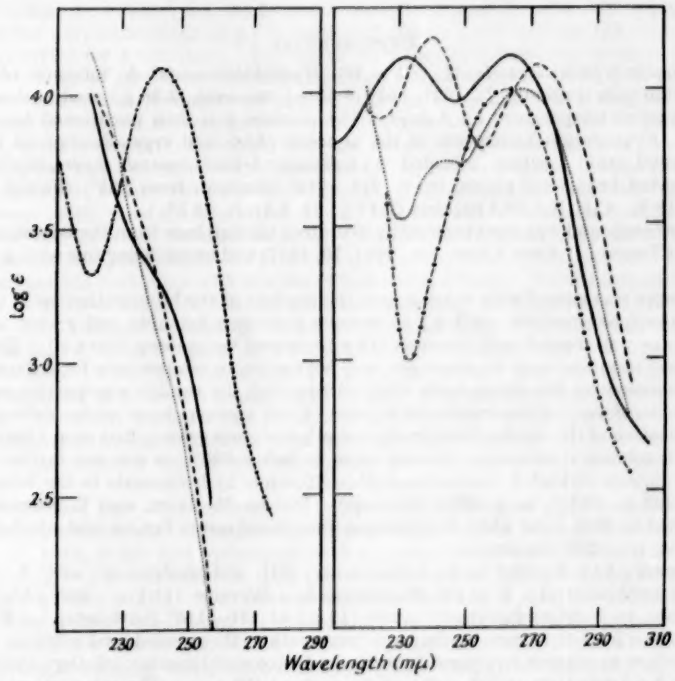


FIG. 1. 2 : 6-*Diamino*-4 : 4-*dimethyl*-1 : 3 : 5-*thiadiazine* (II) *dihydrobromide, in* N-*hydrochloric acid* (— — — —) *and in methanol* (————). *Thiodiformamidine dihydrobromide* (III), *in* N-*hydrochloric acid* (. . . . .) *and in methanol* (— · — · —).

FIG. 2. *Jaffé's base* (X), *in methanol* (————). *Amidinothiourea* (XI), *in methanol* (— — — —) *and in* N-*hydrochloric acid* (— · — · —). *Amidinothiourea hydrochloride, in methanol* (. . . . .).

Marshall and Walker, *J.*, 1951, 1004). Further, the conditions described by Grote, *i.e.*, saturated sodium hydrogen carbonate solution, appeared to be optimal for the development of colour by these substances. On the other hand, the dihydrobromides of 2 : 6-diamino-4 : 4-dimethyl-1 : 3 : 5-thiadiazine (II) and thiodiformamidine gave bluish-purple colours when examined under Grote's standard conditions but the colours were rather fugitive. In the presence of saturated borax, however, the Grote reagent gave intense purple-red colours with the dihydrobromides of the thiadiazine (II) and thiodiformamidine, which faded only very slowly in the course of several days. Buffering by borax also appeared to be more satisfactory for the development of the more transient deep rose-pink colour given by cyanide-reduced cystine with the Grote reagent. On the contrary, the former group of substances, giving green, blue-green, or blue colours with the Grote reagent in saturated sodium hydrogen carbonate, did not develop as intense colours in presence of

borax, and the colours were more fugitive under these conditions. Obviously the components of the Grote reagent, acting differentially with sulphur compounds of distinct types, have different pH optima for colour development, and the test should be applied both with sodium hydrogen carbonate, as Grote described, and with borax. Tschugaeff's reagent (diphenylmethylene chloride) (*Ber.*, 1902, **35**, 2482) was found to be of very restricted application as it failed to give the characteristic blue colour of thiobenzophenone with any of the above cyclic compounds within 5 minutes at 150° (bath-temperature), with the exception of ethylenethiourea, which gave a blue colour within 10 seconds at 150°. The open-chain compounds, thiourea, mono- and di-methylthiourea, amidinothiourea and (*p*-chlorophenylamidino)thiourea all gave blue colours within 5 seconds at 150°.

Experimental

2 : 4-*Diamino-5-phenylthiazole* (I; R = H) *Hydrohalides.*—(*a*) A mixture of α-chloro-α-phenylacetonitrile (Ingham, *J.*, 1927, 695) (6·55 g.), thiourea (3·36 g.), and acetone (10 c.c.) was kept at room temperature for 3 days. The mixture was then partitioned between ether and water. Evaporation to dryness of the aqueous phase and crystallisation of the residue from methanol–ethyl acetate afforded 2 : 4-*diamino-5-phenylthiazole hydrochloride* (7·1 g., 72%), elongated hexagonal plates, m. p. 273—274° (decomp. from 235°) (Found: C, 47·6; H, 4·5; N, 18·2. $C_9H_9N_3S$,HCl requires C, 47·5; H, 4·4; N, 18·5%).

The same compound was also obtained by liberating the free base from the benzenesulphonate (Dodson and Turner, *J. Amer. Chem. Soc.*, 1951, **73**, 4517) and neutralizing this with hydrochloric acid.

(*b*) Nitrogen was passed with stirring over the product of the bromination (as in *Org. Synth.*, **28**, 55) of phenylacetonitrile (29·3 g.) to remove hydrogen bromide and excess of bromine, and the residue was treated with thiourea (19 g.) followed by acetone (300 c.c.). The mixture, which warmed spontaneously to about 40°, was kept at room temperature for 4 days. Solvent was then removed on the steam-bath with stirring and the residue was partitioned between water and chloroform. Evaporation to dryness of the aqueous layer under reduced pressure and crystallisation of the residue from methanol–ethyl acetate gave as first crop a small quantity (3·83 g.) of a colourless substance showing no m. p. below 360°; it was not further examined. The mother-liquors yielded 2 : 4-diamino-5-phenylthiazole hydrobromide in the form of colourless prisms (26 g., 38%), m. p. 260° (decomp.). Davies, Maclaren, and Wilkinson (*J.*, 1950, 3491) obtained an 83% yield when this reaction was carried out in hot, or cold, alcoholic solution and record m. p. >250° (decomp.).

2 : 6-*Diamino*-4 : 4-*dimethyl*-1 : 3 : 5-*thiadiazine* (II) *Dihydrobromide and* 2 : 4-*Diamino-5*-p-*chlorophenylthiazole* (I; R = Cl) *Hydrobromide.*—Bromine (11·1 g.) was added dropwise during 15 min. to *p*-chlorophenylacetonitrile (10 g.) at 110—115° (bath-temp.). The mixture was heated for a further 15 min. at the same temperature, then cooled, and nitrogen was passed over the surface to remove hydrogen bromide and excess of bromine (cf. *Org. Synth.*, **28**, 55). Thiourea (5·5 g.) was then added, followed by acetone (50 c.c.). The mixture, which warmed spontaneously to about 50°, was kept at room temperature for 4 days. After dilution with water and several extractions with ether the aqueous phase was evaporated to dryness under reduced pressure. Crystallisation of the residue from methanol–ethyl acetate afforded, as first crop, colourless plates (3·34 g., 29% based on thiourea) of 2 : 6-*diamino*-4 : 4-*dimethyl*-1 : 3 : 5-*thiadiazine* (II) *dihydrobromide*, m. p. 221—222°; the ultraviolet absorption spectrum showed a shoulder at ~240 mμ (log ε ~3·3) in MeOH, and only end-absorption in N-hydrochloric acid (Found: C, 18·7; H, 3·8; N, 17·4; Br, 49·0. $C_5H_{10}N_4S$,2HBr requires C, 18·8; H, 3·8; N, 17·5; Br, 49·9%).

Fractional crystallisation of the material remaining in the mother-liquors from methanol–ethyl acetate gave colourless needles (5·9 g.; 23%) of 2 : 4-*diamino-5*-p-*chlorophenylthiazole* (I; R = Cl) *hydrobromide*, m. p. 260° (decomp.) (Found: C, 35·2; H, 2·9; N, 13·4. $C_9H_8N_3ClS$,HBr requires C, 35·2; H, 3·0; N, 13·7%).

Thiodiformamidine Dihydrochloride.—A solution of thiourea (14·5 g., 1 mol.) in absolute alcohol (250 c.c.) containing dissolved hydrogen chloride (5·5% w/v; 2 mols.) was added to a solution of cyanamide (8 g.) in a small volume of absolute alcohol. Heat was evolved and a white crystalline solid rapidly separated. After an hour the mixture was cooled, and the product (30·2 g., 84%), m. p. (crude) 181—182° (effervescence) was collected and dried. Recrystallisation from methanol–ethyl acetate (1 : 1) gave plates of thiodiformamidine dihydrochloride,

m. p. 182° (effervescence) (Found: C, 12·9; H, 4·2; N, 29·6. Calc. for $C_2H_6N_4S,2HCl$: C, 12·6; H, 4·2; N, 29·3%). Chabrier, Renard, and Renier (*loc. cit.*) record m. p. 178°.

Thiodiformamidine Dihydrobromide (III).—In a similar manner, cyanamide (3 g.), alcoholic hydrogen bromide (140 c.c. of 8·2% w/v), and thiourea (5·4 g.) afforded *thiodiformamidine dihydrobromide* (14·4 g., 72%), which separated from 90% aqueous acetic acid in colourless flattened needles, m. p. 205—206° (effervescence); ultraviolet light absorption, $\lambda_{max.}$ 242 mμ (log ε 4·10) in MeOH, only end-absorption in N-hydrochloric acid (Found: C, 8·7; H, 3·0; N, 19·9; Br, 56·8. $C_2H_6N_4S,2HBr$ requires C, 8·6; H, 2·9; N, 20·0; Br, 57·1%). A 1% aqueous solution had pH 2·03.

When the hydrogen bromide was supplied in the form of concentrated aqueous solution diluted with about 6 volumes of ethanol the yield dropped to about 50%.

2 : 6-*Diamino*-4 : 4-*dimethyl*-1 : 3 : 5-*thiadiazine* (II) *Dihydrobromide*.—A solution of thiodiformamidine dihydrobromide (5 g.) in methanol (60 c.c.) and acetone (50 c.c.) was kept at room temperature for 4—10 days. The use of methanol as solvent was necessary on account of the insolubility of powdered thiodiformamidine dihydrobromide in bulk in acetone. The solvent was removed as thoroughly as possible at room temperature in a vacuum, finally with two additions of absolute alcohol, giving crystalline material contaminated by gum. The gum was dissolved out in absolute alcohol (10 c.c.), and the crystalline material (1·96 g.) was collected. Recrystallisation from methanol–ethyl acetate (1 : 2) gave colourless plates (1·64 g., 29%) of 2 : 6-diamino-4 : 4-dimethyl-1 : 3 : 5-thiadiazine (II) dihydrobromide, m. p. 221—222° (effervescence) with prior discoloration, having an infrared absorption spectrum identical with that of the specimen obtained as above (Found: C, 18·7; H, 3·8; N, 17·4%). A 1% aqueous solution had pH 2·20.

No condensation took place with free thiodiformamidine base. Thiodiformamidine dihydrochloride (1·91 g.) was added to ethanol (20 c.c.) containing sodium ethoxide (from 0·46 g. of sodium), sodium chloride separating. After *ca.* 10 min. acetone (10 c.c.) was added and the mixture was kept at room temperature for 3 days. The sodium chloride was separated and the calculated volume of N-hydrobromic acid (20 c.c.) was added. The mixture was then taken to dryness below 40° in a vacuum (Craig, *Analyt. Chem.*, 1950, **22**, 1462), finally with two additions of ethanol. The crude product (2·9 g.) had m. p. 175—183° (effervescence) raised to 192—193° (effervescence) on crystallisation from methanol–ethyl acetate. The infrared absorption spectrum of this material showed excellent agreement with that of thiodiformamidine dihydrobromide.

Amidinothiourea (XI) *Hydrochloride*.—4 : 6-Diamino-2-mercapto-1 : 3 : 5-thiadiazine (16 g.), obtained from dicyandiamide and carbon disulphide (U.S.P. 2,364,594; Birtwell, Curd, Hendry, and Rose, *J.*, 1948, 1649), was hydrolysed with concentrated hydrochloric acid as described in the same patent. The solution was then concentrated under reduced pressure to small bulk and propan-1-ol was added. The mixture was warmed and a small quantity of solid was rejected. The solution was taken to dryness several times with ethanol, and the residue was taken up in hot ethanol (*ca.* 50 c.c.) (charcoal) and freed from a small insoluble residue. On cooling and scratching, small stout colourless prisms (5·2 g.) with pointed ends separated, m. p. 172—173° (effervescence); recrystallisation from ~6 parts of ethanol raised the m. p. to 177—178° (effervescence); ultraviolet light absorption, $\lambda_{max.}$ 244, 267 mμ (log ε 3·74, 4·01) in MeOH, 262—263 mμ (log ε 4·01) in N-HCl (Found: C, 15·7; H, 4·4; N, 36·1. Calc. for $C_2H_6N_4S,HCl$: C, 15·5; H, 4·5; N, 36·2%). Rathke (*Ber.*, 1878, **11**, 962) records an analysis but no m. p., while U.S.P. 2,364,954 records neither. The m. p. is almost the same as that, 175—176°, recorded for the free base (cf. Birtwell *et al.*, *loc. cit.*). A 1% aqueous solution had pH 3·70.

Free amidinothiourea was obtained by the method of Birtwell *et al.* (*loc. cit.*); ultraviolet light absorption, $\lambda_{max.}$ 240, 272 mμ (log ε 4·20, 4.10) in MeOH.

4-*Amino*-1 : 2-*dihydro*-6-*mercapto*-2 : 2-*dimethyl*-1 : 3 : 5-*triazine* (XII).—(*a*) A mixture of amidinothiourea (2·36 g.) and acetone (75 c.c.) containing piperidine (0·5 c.c.) was kept at 37° for 18 hr. The crystalline solid, m. p. 178—180°, was collected and a second similar crop was obtained by concentrating the mother-liquors (total yield, 1·75 g., 55%). Recrystallisation from water afforded 4-*amino*-1 : 2-*dihydro*-6-*mercapto*-2 : 2-*dimethyl*-1 : 3 : 5-*triazine* (XII) in the form of colourless flattened needles, m. p. 192—193°; ultraviolet light absorption, $\lambda_{max.}$ 277 mμ (log ε 4·16), shoulder at ~260 mμ (log ε ~4·05) in MeOH (Found: C, 37·4; H, 6·5; N, 35·3. $C_5H_{10}N_4S$ requires C, 38·0; H, 6·4; N, 35·4%). The *picrate* separated from ethanol in yellow rhombs, m. p. 216—217° (Found: C, 34·3; H, 3·6; N, 25·0. $C_5H_{10}N_4S,C_6H_3O_7N_3$ requires C, 34·1; H, 3·4; N, 25·3%).

(*b*) 4-Amino-1 : 2-dihydro-2 : 2-dimethyl-6-methylthio-1 : 3 : 5-triazine (XIII) (obtained in 39% yield from *S*-methyl*iso*thiourea and acetone by the method of Birtwell *et al.*, *loc. cit.*) (0·50 g.) was treated in pyridine (3 c.c.) containing triethylamine (0·4 g.) with a stream of hydrogen sulphide for 4 hr. The solvents were then removed under reduced pressure and the residue was shaken with water (3 c.c.). The solid was collected and recrystallisation from water gave the mercapto-compound (0·3 g., 65%), identical with that prepared as in (*a*) (above), m. p. and mixed m. p. 192—193°.

Condensation of Acetone and of Mesityl Oxide with Thiourea in Presence of Hydrobromic Acid. 2-Amino-4 : 6 : 6-trimethyl-1 : 3-thiazine (XIV) *Picrate.*—(*a*) A mixture of thiourea (7·6 g.), concentrated (48%) aqueous hydrobromic acid (20 c.c.), and acetone (100 c.c.) was kept at room temperature for 6 days. The solvent was removed under reduced pressure and the semi-solid residue was treated with aqueous sodium picrate solution. Recrystallisation from alcohol then afforded yellow needles (4·32 g., 11%) of *2-amino-4 : 6 : 6-trimethyl-1 : 3-thiazine* (XIV) *picrate*, m. p. 196—198° (Found : C, 40·3; H, 3·9; N, 18·2. $C_7H_{12}N_2S,C_6H_3O_7N_3$ requires C, 40·5; H, 3·9; N, 18·2%).

(*b*) A mixture of mesityl oxide (50 c.c.), thiourea (7·6 g.), and concentrated (48%) aqueous hydrobromic acid (20 c.c.) was kept at room temperature for 8 days. The solvent and excess of hydrobromic acid were removed under reduced pressure and the dark residue was treated with aqueous sodium picrate, affording a picrate (29·8 g., 78%), identical with that obtained as in (*a*) (above), m. p. and mixed m. p. 196—198°.

This picrate is probably the same as that of Taylor (*loc. cit.*) who records m. p. 193—194° for " thiocarbamide-acetone picrate."

4 : 5-Dihydro-2-mercapto-4 : 4 : 6-trimethylpyrimidine (XV) (cf. Robbins, U.S.P. 2,539,480; Hill, B.P. 633,353).—A mixture of ammonium thiocyanate (38 g.), mesityl oxide (50 g.), and toluene (50 g.) was boiled under reflux for 8 hr. with the conventional Dean and Stark apparatus, until no further separation of water (8·7 c.c.; calc., 9·0 c.c.) took place. The light brown residue (64 g., 82%) was washed with water and with benzene, and dried at 100°. Recrystallisation from glacial acetic acid yielded colourless needles of 4 : 5-dihydro-2-mercapto-4 : 4 : 6-trimethylpyrimidine, m. p. 253° (decomp.); ultraviolet light absorption, $\lambda_{max.}$ 261—263 mμ (log ε 4·06) (Found : C, 53·5; H, 7·5; N, 17·6. Calc. for $C_7H_{12}N_2S$: C, 53·8; H, 7·7; N, 17·9%). Traube (*Ber.*, 1894, **27**, 277) records m. p. 249° for this substance, prepared from diacetonamine oxalate and potassium thiocyanate, while Mathes, Stewart, and Swedish (*J. Amer. Chem. Soc.*, 1948, **70**, 1452) record m. p. 254—255° for the product from 4-methyl-4-*iso*thiocyanatopentan-2-one (Mathes, *ibid.*, 1953, **75**, 1747) and ammonia. The substance was insoluble in both acid and alkali, and did not form a picrate.

A portion (5·0 g.) was refluxed in ethanol with methyl iodide (4 c.c., 2 mol.) for 3 hr. Removal of solvent under reduced pressure and recrystallisation of the residue from methanol–ethyl acetate afforded colourless needles (8·3 g., 87%) of *4 : 5-dihydro-4 : 4 : 6-trimethyl-2-methylthiopyrimidine hydriodide*, m. p. 162—163° (Found : C, 32·7; H, 5·5; N, 9·2. $C_8H_{14}N_2S,HI$ requires C, 32·2; H, 5·0; N, 9·4%).

This hydriodide (2·98 g.), in a mixture of triethylamine (2·2 g.) and pyridine (10 c.c.), was treated with a stream of hydrogen sulphide for 3 hr. Pouring the mixture into ice-water gave 4 : 5-dihydro-2-mercapto-4 : 4 : 6-trimethylpyrimidine (1·40 g., 90%), m. p. and mixed m. p. 251°.

Jaffé's Base [*4 : 5-Dihydro-1-(4 : 5-dihydroglyoxalin-2-yl)-2-mercaptoglyoxaline* (X)].—This substance was prepared from ethylenethiourea (IV) *via* the disulphide (VII) hydroperiodide as described by Johnson and Edens (*ibid.*, 1942, **64**, 2706); ultraviolet light absorption, $\lambda_{max.}$ 231—232, 263—264 mμ (log ε 4·13, 4·13) in MeOH.

A 1% aqueous solution of the hydrochloride (Johnson and Edens, *ibid.*, 1941, **63**, 1058) had a pH of 4·74. The hydrochloride showed the following ultraviolet light absorption : $\lambda_{max.}$ 231, 265 mμ (log ε 4·09, 4·00) in MeOH; 233—234, 261—262 mμ (log ε 4·18, 4·10) in N-HCl.

Physical Measurements.—Ultraviolet absorption measurements were made with a Unicam SP. 500 quartz spectrophotometer; pH measurements were made with a Doran " alkacid " glass electrode; infrared absorption spectra were observed in pressed potassium bromide discs.

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Calculated Bond Lengths in Some Cyclic Compounds. Part III. Benzoic Acid.*

By T. H. Goodwin.

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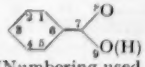
Energy levels, bond orders, and bond lengths have been deduced as accurately as possible for benzoic acid by the molecular-orbital method with both neglect and inclusion of overlap. The results have been compared with the *X*-ray measurements by Sim, Robertson, and Goodwin (*Acta Cryst.*, 1955, **8**, 157) and show a mean deviation from these of only $|\Delta| = 0{\cdot}014$ Å although it has usually been supposed that with heterocyclic compounds the calculations cannot be relied on to nearer than 0·05 Å.

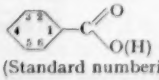
Wave-mechanical studies of benzene, naphthalene, and other aromatic hydrocarbons have been made during several years by both the valency-bond and the molecular-orbital method. Although the qualitative use of the valency-bond method by organic chemists in the form of " resonating structures " to explain the properties of hydrocarbons and their derivatives is well established, in this Series the molecular-orbital technique is being applied to calculate bond lengths for comparison with experimental measurements made chiefly by *X*-ray crystallography. The crystal structure of benzoic acid has recently been published by Sim, Robertson, and Goodwin (*Acta Cryst.*, 1955, **8**, 157) who have measured the interatomic distances with a standard deviation of about 0·020 Å. The present work was carried out to compare these experimental results with the most accurate values calculable by the molecular-orbital technique.

Parameters for secular equations

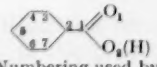
Three sets of calculations are presented. In the first two, described as methods 1 and 2, different values were used for the Coulomb integrals α, but the resonance (exchange) integrals H were the same and the overlap integrals S were neglected. In method 3 the α's were given the same values as in method 2, the H's were modified slightly in the light of the results of method 2, and the overlap integrals were included. The values of these parameters were selected as follows.



(I*a*) (Numbering used in these calculations.)



(I*b*) (Standard numbering.)



(I*c*) (Numbering used by Sim, Robertson, and Goodwin.)

(a) *Coulomb Integrals.*—In benzoic acid (I) each of the seven carbon atoms and one oxygen atom supplies one p_z electron to the π-molecular-orbital system, while the hydroxyl-oxygen atom supplies its two p_z electrons. Thus nine molecular orbitals accommodate ten electrons. Now, in applying the molecular-orbital treatment to the π-electron system of benzoic acid, we suppose all these ten electrons to have been removed from the molecule. The Coulomb integral α of an atom then represents the net attraction of its nucleus and other electrons (σ-binding and non-binding) for the π-electrons which are to be fed in in pairs to each π-molecular orbital in succession. This attraction differs with the kind of atom and with the number of p_z electrons which it has lost. Thus $|\alpha_{\text{oxygen}}| > |\alpha_C|$, where C represents a standard aromatic carbon atom and, in particular, $\alpha_8 = \alpha_C + m\beta$ and $\alpha_9 = \alpha_C + m'\beta$, where $m' \approx 2m$ since atom 9 contributes two and atom 8 only one electron to the π-system. However these electron-affinity differences between oxygen and carbon induce changes in the Coulomb terms of the carbon atoms throughout the molecule. These changes (cf. Dewar, *Nature*, 1950, **166**, 790) have been supposed to be given by $\delta_i = 0{\cdot}6^n\beta$ in method 1 and by $\delta_i = 2 \times 0{\cdot}3^n\beta$ in methods 2 and 3, n being the number of bonds separating the ith (carbon) atom from oxygen. In setting up the secular equations these corrections were rounded to the second place of decimals. However it was not discovered

* Part II, *J.*, 1955, 1689.

until the calculations of method 1 were complete that a slip had been made in writing the coefficient for the induced Coulomb effect as $0{\cdot}6^n\beta$, which is much too high. The results are therefore presented here simply as a demonstration of the consequences of using this coefficient; no discussion will be given of them.

(b) *Resonance Integrals.*—The parameters H_{rs} selected in methods 1 and 2 are adequately set out in Table 1 and call for no further comment. In method 3 the standard value $\beta_{1\cdot39}$ (written β in Table 1) was used for all neighbouring atoms of the benzene ring because the bond lengths in this ring were likely to be very closely similar to those in benzene and to show very little variation among themselves. Following Lennard-Jones (*Proc. Roy. Soc.*, 1937, *A*, **158**, 280), Mulliken, Rieke, and Brown (*J. Amer. Chem. Soc.*, 1941, **63**, 48) give a Table showing the variation of β with interatomic distance and, this being used, H_{67} was set equal to $0{\cdot}72\beta_{1\cdot39}$. For the bonds involving oxygen β_{78} was again taken as $\sqrt{2}\beta_{1\cdot39}$(C–C) as in method 2 but β_{79} was evaluated as follows: the orders of bonds 7—8 and 7—9 obtained by method 2 were 0·542 and 0·723 respectively. Had these been between carbon atoms they would have corresponded to lengths of 1·373 and 1·427 Å and so to β values of $1{\cdot}05\beta_{1\cdot39}$ and $0{\cdot}87\beta_{1\cdot39}$. The same law of variation of β with distance being assumed for C–O and C–C bonds, this leads to $\beta_{79} = 0{\cdot}87\sqrt{2}\beta_{1\cdot39}/1{\cdot}05 = 1{\cdot}17\beta_{1\cdot39}$.

(c) *Overlap Integrals.* (*Method 3 only.*)—For the ring bonds S_{rs} was taken as 0·25. By using a linear interpolation between the values of 0·25 and 0·19 given by Mulliken, Rieke, Orloff, and Orloff (*J. Chem. Phys.*, 1949, **17**, 1257) for carbon atoms respectively 1·39 and 1·54 Å apart a figure of 0·22 was adopted for S_{67} on the basis of the length calculated in method 2. In a similar way interpolation between 0·23 and 0·14 for carbon and oxygen atoms respectively 1·22 and 1·43 Å apart gave $S_{78} = 0{\cdot}23$ and $S_{79} = 0{\cdot}20$.

These various sets of parameters are summarised in Table 1.

TABLE 1. *Parameters for benzoic acid.*

	Method		
	1	2	3
Coulomb integrals a_r			
α_C	—	—	$-3{\cdot}52\beta$
$\alpha_1 - \alpha_C = \alpha_5 - \alpha_C$	$0{\cdot}22\beta$	$0{\cdot}05\beta$	$0{\cdot}05\beta$
$\alpha_3 - \alpha_C = \alpha_4 - \alpha_C$	$0{\cdot}13\beta$	$0{\cdot}02\beta$	$0{\cdot}02\beta$
$\alpha_2 - \alpha_C$	$0{\cdot}08\beta$	0	0
$\alpha_6 - \alpha_C$	$0{\cdot}36\beta$	$0{\cdot}18\beta$	$0{\cdot}18\beta$
$\alpha_7 - \alpha_C$	$0{\cdot}6\beta$	$0{\cdot}6\beta$	$0{\cdot}6\beta$
$\alpha_8 - \alpha_C$	$0{\cdot}5\beta$	$1{\cdot}25\beta$	$1{\cdot}25\beta$
$\alpha_9 - \alpha_C$	β	2β	2β

	Method		
	1	2	3
Resonance integrals H_{rs}			
r and s Neighbours within ring	β	β	β
H_{67}	β	β	$0{\cdot}72\beta$
H_{78}	$\sqrt{2}\beta$	$\sqrt{2}\beta$	$\sqrt{2}\beta$
H_{79}	$\sqrt{2}\beta$	$\sqrt{2}\beta$	$1{\cdot}17\beta$
All others	0	0	0
Overlap integrals S_{rs}			
r and s Neighbours within ring	0	0	0·25
S_{67}	0	0	0·22
S_{78}	0	0	0·23
S_{79}	0	0	0·20
All others	0	0	0

EVALUATION OF BOND ORDERS WHEN OVERLAP IS INCLUDED

The inclusion of the induced Coulomb terms in methods 1 and 2 makes the expansion and solution of the secular determinant slightly more laborious than usual but by employing such of the techniques described in Part I (*J.*, 1955, **1683**) as are applicable some reduction in the work is possible. Thereafter the calculation of bond orders, etc., calls for no comment.

For a hydrocarbon the bonds of which are all of approximately the same order and hence have the same value of the overlap integral the secular determinant with overlap differs from that without only in that the non-zero elements lying off the leading diagonal are $\beta - SE$ instead of β. A simple transformation then gives the energy levels and the delocalisation energy in units of $\gamma = \beta - \alpha S$ instead of β. However, with heteromolecules this is not possible because of the inequality of the overlap, Coulomb, and exchange integrals involved. In particular, in the present case, it was necessary to express the Coulomb term of a standard carbon atom as a multiple of $\beta_{1\cdot39}$. This was done as follows.

Inspection of a table such as Hartmann's ("Theorie der chemischen Bindung," Springer, Berlin, 1954, pp. **267**, **268**) shows that the ratio of the delocalisation energy in units of β to that in units of γ is roughly constant over a wide range of hydrocarbons and closely constant over a smaller range of very similar compounds such as benzene, naphthalene, and anthracene. An even wider range of similar information, closely correlated with molecular size and constitution and leading to the same conclusion is obtainable from Bradburn, Coulson, and Rushbrooke's

work (*Proc. Roy. Soc. Edinburgh*, **1948**, **62**, 336) in which the delocalisation energies *per carbon atom* in units of β and γ can be derived by subtracting unity from each entry in their Table 1 and 0·8 from each entry in their Table 4, the π-energy per carbon atom in ethylene being 1β and 0·8γ respectively. If it is then assumed as a first approximation that the delocalisation energies calculated by both these methods represent the same thing, *viz.*, the difference between observed and calculated heats of formation, they may be used to evaluate α. Thus, benzene being selected for an obvious reason, though styrene might have been better, the delocalisation energies are $2{\cdot}00\beta = 1{\cdot}067\gamma = 1{\cdot}067(\beta - \alpha S)$. Writing $S = 0{\cdot}25$ as usual this gives $\alpha = -3{\cdot}52\beta$ (styrene would have given $\alpha = -4{\cdot}01\beta$), a value agreeing with the ratio α/β implied by Mulliken, Rieke, and Brown (*loc. cit.*). If it is then reasonable to suppose that this value of α can be taken as applying to the " standard aromatic arbon atom " in benzoic acid the elements of the secular determinant can be expressed in terms of β and E alone, and hence the energy levels can be deduced as in methods 1 and 2. Incidentally, the change in the origin of energy does not affect the ratio of β/γ as might at first sight be expected.

Table 2 gives these energy levels for the molecular orbitals of the π-electrons in benzoic acid

TABLE 2. *π-Electron molecular-orbital energy levels (E_i) for benzoic acid in order of increasing energy.*

	Method				Method		
i	1	2	3	i	1	2	3
1	$\alpha + 2{\cdot}9836\beta$	$\alpha + 3{\cdot}3816\beta$	$-0{\cdot}2948\beta$	6	$\alpha - 0{\cdot}6157\beta$	$\alpha - 0{\cdot}5601\beta$	$-5{\cdot}0967\beta$
2	$\alpha + 2{\cdot}0946\beta$	$\alpha + 2{\cdot}0513\beta$	$-1{\cdot}0031\beta$	7	$\alpha - 0{\cdot}8285\beta$	$\alpha - 0{\cdot}9651\beta$	$-5{\cdot}9460\beta$
3	$\alpha + 1{\cdot}1774\beta$	$\alpha + 1{\cdot}6024\beta$	$-1{\cdot}8043\beta$	8	$\alpha - 1{\cdot}4876\beta$	$\alpha - 1{\cdot}3951\beta$	$-7{\cdot}4967\beta$
4	$\alpha + 1{\cdot}1758\beta$	$\alpha + 1{\cdot}0923\beta$	$-1{\cdot}9879\beta$	9	$\alpha - 1{\cdot}9986\beta$	$\alpha - 2{\cdot}0723\beta$	$-11{\cdot}6932\beta$
5	$\alpha + 0{\cdot}7390\beta$	$\alpha + 1{\cdot}0351\beta$	$-2{\cdot}0074\beta$				

as calculated for each set of parameters while Tables 3 and 4 give the corresponding electron distributions, q, mobile bond orders, p, etc. The quantities q and p for method 3 were calculated as indicated by Chirgwin and Coulson (*Proc. Roy. Soc.*, 1950, *A*, **201**, 196). Since resonance and overlap integrals have been neglected except between nearest neighbour orbitals the combined effect of the carbonyl-oxygen atom 8 and the hydroxyl-oxygen atom 9 is the same at both atoms 1 and 5. Hence the ring shows axial symmetry about the line joining atoms 3 and 6. The theoretical bond lengths L_1 and L_2 in Table 4 are derived from the bond orders by the correlations indicated in Part I (*loc. cit.*) while L_M gives the measured lengths reported by Sim, Robertson, and Goodwin (*loc. cit.*); $\Delta = L_M - L_2$.

DISCUSSION

In the crystallographic study of benzoic acid it was found that though the benzene ring may be regarded as strictly planar the carbon atom numbered 7 in this paper and the oxygen atom numbered 9 are 0·042 and 0·068 Å respectively from the plane of the ring. These deviations, though small, appear to be significant because they are several times as

TABLE 3. *π-Electron distribution (q) in benzoic acid.*

Atom, numbered according to			Method			Atom, numbered according to			Method		
1*a*	1*b*	1*c*	1	2	3	1*a*	1*b*	1*c*	1	2	3
1, 5	2, 6	3, 7	0·991	0·949	0·976	7	C	1	0·981	0·810	0·838
2, 4	3, 5	4, 6	0·987	0·999	1·000	8 *	=O	O_1	*1·402*	*1·538*	*1·447*
3	4	5	0·949	0·943	0·976	9 *	–O–	O_2	*1·646*	*1·746*	*1·751*
6	1	2	1·067	1·070	1·036						

* Oxygen atoms.

great as the standard deviation of position of a carbon or an oxygen atom. The molecular-orbital treatment adopted here is based on the assumption of an entirely planar molecule, first, because this is the most obvious molecular structure resulting from maximum overlap of neighbouring atomic orbitals throughout the molecule, secondly, because the extra delocalisation energy of benzoic acid over that of benzene (see, *e.g.*, Pauling, " Nature of the Chemical Bond," Cornell Univ. Press, New York, 1944, p. 139) indicates that the

π-electron system must extend into the carboxyl group which one would therefore expect to be coplanar with the ring, and, thirdly, because the calculations were well under way before the *X*-ray results were completed. In any case it is not unreasonable to suppose that the small deviations from planarity noted experimentally are, if genuine (as they appear to be), the results of crystal packing rather than fundamental to the isolated molecule.

The most obvious thing about the data in Table 4 is, perhaps, the close agreement between L_M and the values of L_2 calculated by methods 2 and 3. Coulson (*Proc. Roy. Soc.*,

TABLE 4. *Mobile bond orders (p) with calculated and observed bond lengths (L) in benzoic acid.*

Bond, numbered according to			Method 1		Method 2				Method 3				
1a	*1b*	*1c*	p_{12}	L_2	p_{12}	L_1	L_2	Δ	p_{12}	L_1	L_2	Δ	L_M
1–2	2–3	3–4	0·740	1·370	0·677	1·388	1·383	0·03	0·671	1·389	1·385	0·02	1·41
1–6	1–2	2–3	0·632	1·395	0·620	1·400	1·399	−0·01	0·640	1·396	1·393	0·00	1·39
2–3	3–4	4–5	0·661	1·387	0·659	1·391	1·387	−0·03	0·664	1·390	1·386	−0·03	1·36
6–7	1–C	1–2	0·303	1·486	0·346	1·459	1·482	0·00	0·291	1·468	1·487	−0·01	1·48
7–8 *	C=O	C–O_1	*0·748*	*1·226*	*0·723*	*1·233*	*1·233*	*0·01*	*0·771*	*1·219*	*1·219*	*0·02*	*1·24*
7–9 *	C–O	C–O_2	*0·587*	*1·271*	*0·542*	*1·284*	*1·284*	*0·01*	*0·532*	*1·286*	*1·286*	*0·00*	*1·29*

* Oxygen atoms.

1951, *A*, **207**, 91) and Coulson, Daudel, and Robertson (*ibid.*, p. 306) show that for aromatic hydrocarbons molecular-orbital calculations and good *X*-ray work both permit estimation of bond lengths to about 0·02 Å and that the results obtained by the two methods agree within the same limits. Coulson (*loc. cit.*) also indicates that for heteromolecules the agreement is not usually closer than 0·05 Å. In Table 4 the agreement is much better the average | Δ | for the nine bonds, being only 0·017 Å in method 2 and 0·014 Å in method 3. Clearly the reliability of the calculations must depend on the extent to which the system can be regarded as a hydrocarbon perturbed by heteroatoms. In benzoic acid three of the ten electrons in the nine-atom π-orbital system are supplied by the two oxygen atoms, so that a profound effect would be expected. Actually, by comparison with styrene (Pullman and Pullman, " Les Théories Électroniques de la Chimie Organique," Masson et Cie., Paris, 1952, p. 598) it seems that the effect of the oxygen atoms scarcely extends into the ring. This is shown by the following bond orders, the hydrocarbon being numbered in accordance with the scheme used in this paper for benzoic acid :

Bond	1–2	1–6	2–3	6–7	7–8
Benzoic acid	0·674	0·640	0·657	0·286	*0·783* *
Styrene	0·679	0·610	0·659	0·406	0·911

* Bond involving oxygen.

Thus, apart from the bonds in which they are directly concerned, the main effect of the oxygen atoms seems to be a slight lengthening of the extracyclic C–C bond compared with that in styrene. Experimental figures for this liquid are not, of course, available.

Sim, Robertson, and Goodwin (*loc. cit.*) give the standard deviations of the C–C and C–O bonds as 0·016 and 0·014 Å respectively, which could be regarded as accounting for all the discrepancies in Table 4 except those for the bonds 1–2 and 2–3. The calculations require the ring bonds to be scarcely distinguishable in length but the bond 1–2 is longer and 2–3 shorter than the calculated length, though by amounts which are only about twice the standard deviation and therefore not definitely significant. However the difference between 1–2 and 2–3 (0·05 Å) does appear to be significant as was recognised in the report on the measurements where it was pointed out that the difference could not be explained on the basis of any reasonable resonating structures which could be written for benzoic acid. This conclusion, taken with the present results, suggests that the problem is not likely to be resolved without a three-dimensional *X*-ray analysis.

The second point to notice about the figures in Table 4 is that the inclusion of overlap in the calculations has influenced only the extracyclic bonds. It is well known (Chirgwin

and Coulson, *loc. cit.*) that the inclusion of overlap in calculations on hydrocarbons does not alter the bond orders though it must in heteromolecules. The present calculations indicate that the effect is local, reaching only to the first bonds of the ring. This suggests that some of the labour involved in these calculations could be avoided by including overlap only for the bonds nearest to the perturbing heteroatoms. Careful trials would be needed to establish this point since, although it is now established that there is little difference between the results when all overlap integrals are included and when none are, inclusion of some only might give quite wrong bond orders, etc.

In support of the arguments of Part I (*loc. cit.*), the length L_2 of the bond 6–7 obtained by method 2 agrees better with experiment than L_1, although in method 3 the two lengths straddle the experimental value.

Turning to Table 3 there is, of course, no change in the sequence of π-electron distributions when overlap is included, though the charges on all the atoms tend to be reduced. It will be noted that since only 1·751 (1·746) of the two p_z electrons are formally associated with the hydroxyl-oxygen atom 9 this atom carries a positive charge of 0·249 (0·254) due to this π-electron deficiency while there is a corresponding negative charge of 0·447 (0·538) on the carbonyl-oxygen atom 8.

If the charges recorded in Table 3 are used to calculate the contribution of the π-electrons to the dipole moment of the molecule a value of 3·84 D is obtained in a direction nearly along the bond 7→8. This may be contrasted with the following experimental results: 1·0 D in benzene at 25° (Williams and Allgeier, *J. Amer. Chem. Soc.*, 1927, **49**, 2416), 0·56 D in benzene at 22° (Briegleb, *Z. phys. Chem.*, 1930, *B*, **10**, 205), 1·71 D in dioxan at 25° (Wilson and Wenzke, *J. Amer. Chem. Soc.*, 1935, **57**, 1265), 1·78 D in dioxan at 30° (Brooks and Hobbs, *ibid.*, 1940, **62**, 2851), and 1·64 D in benzene at 30° (Pohl, Hobbs, and Gross, *Ann. New York Acad. Sci.*, 1940, **40**, 389). There are many possible causes of this discrepancy, particularly that, though the π-dipole moment would be expected to make the greatest contribution to the total moment, contributions would also be expected from the σ-bonds and from the non-bonding electrons. The σ-bond moment can be allowed for by using Orgel, Cottrell, Dick, and Sutton's data (*Trans. Faraday Soc.*, 1951, **47**, 116) and amounts to 1·2 D along the bond 6→7. This combines vectorially with the π-moment to give a total moment of 4·35 D at about 56° to the bond 6→7, but it seems unlikely that the contributions of the non-bonding electrons, etc., can account for this even larger discrepancy. However the calculations are for an isolated molecule whereas the measurements are for solutions from which the solvent effects cannot be satisfactorily eliminated and in which the molecules are dimeric. *X*-Ray examination of many carboxylic acids leads one to expect that in solution the dimers will be centrosymmetrical and hence will have no dipole moment or at most only a small one due to thermal disturbance of the centrosymmetrical ideal. Thus the observed and calculated moments are not strictly comparable but do in fact differ in the expected direction.

Professor J. M. Robertson, F.R.S., is thanked for his interest, and Professor C. A. Coulson, F.R.S., for much helpful advice and discussion.

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Directing Effects in Inorganic Substitution Reactions. Part I. A Hypothesis to Explain the trans-*Effect.*

By J. Chatt, L. A. Duncanson, and L. M. Venanzi.

[Reprint Order No. 6500.]

The hypothesis that *trans*-directing ligands in square planar and octahedral complex compounds exert their directing effects in substitution reactions because they co-ordinate by double bonds is developed, and it is shown how the general phenomenon of the *trans*-effect can be explained. It is supposed that the forces responsible for the directing effect originate mainly in the electron withdrawal, occasioned by dative π-bond formation, from a d_{xz}-orbital of the metal towards the ligand A of high *trans*-effect (Fig. 2). This electron withdrawal will increase the electron affinity of the metal atom and perhaps the strength of σ-bonding to all the other ligands B. However, the electrons are withdrawn mainly from the antinodes remote from A of the *d*-orbital, thus decreasing any tendency of the ligand B in *trans*-position to A to form a dative π-bond. The whole M=B bond will thus be drastically weakened (*i.e.*, more subject to heterolytic fission) if the dative π-bond is an essential component. However, if B, *trans* to A, has little tendency to form dative π-bonds its attachment to the metal could be strengthened by the presence of A.

The operation of the rapid and readily reversible elimination of groups *trans* to ligands A of high *trans*-effect (*i.e.*, high double-bonding capacity) is readily explained if we suppose that *trans*-substitution occurs by an S_N2 (bimolecular) mechanism. Increasing double bonding by A increases the electron affinity of the metal atom and hence the ease of nucleophilic attack. Also, because the electron withdrawal occasioned by A occurs from the antinodes remote from A of the d_{xz}-orbital, the attack takes place there, preferentially displacing the ligand *trans* to A (Fig. 2). Electronically platinum(II) is uniquely constituted for the origin and transmission of a strong *trans*-effect.

Chernyaev (*Ann. Inst. Platine, U.S.S.R.*, 1926, **4**, 243; 1927, **5**, 118) observed that, in the substitution reactions of the complex compounds of platinum(II), the position of substitution depends on the groups or ligands already present in the complex and not on the entering group. Subsequent developments in preparative co-ordination chemistry have served to confirm that strong directing forces operate in guiding the course of substitution in square planar platinous complexes; also that similar, but probably weaker, forces may influence the course of substitution in all complex compounds of inert type, especially of planar palladium(II), and octahedral cobalt(III), rhodium(III), and platinum(IV). The subject of these directing effects and current hypotheses as to their nature have recently been reviewed by Quagliano and Schubert (*Chem. Rev.*, 1952, **50**, 201). However, the effects have received extensive study only in the platinous series of complexes. So far all studies have been essentially qualitative; it is the object of the present series of papers to find a quantitative basis, and extend the study to metals other than platinum.

The laws of substitution as they apply in platinous chemistry may be illustrated by the two reactions:

$$K[NH_3,PtCl_3] + C_2H_4 \longrightarrow \textit{cis}\text{-}[NH_3,C_2H_4,PtCl_2] + KCl$$
$$K[C_2H_4,PtCl_3] + NH_3 \longrightarrow \textit{trans}\text{-}[NH_3,C_2H_4,PtCl_2] + KCl$$

In these, ammonia directs the entering group into a *cis*-position and substitution is slow; ethylene directs it into the *trans*-position, and this substitution is rapid and readily reversible. The analogy between the above substitution reactions and the familiar substitution of benzene is very striking. The *cis*-substitution reaction corresponds to *meta*, and the *trans* to *ortho*- and *para*-substitution reactions. It should therefore be

possible to place the common ligands of inorganic complex chemistry in order of their tendency to direct a second substituent into the *trans*-position. This has been done by chemists of the Russian school but only qualitatively, and a series in approximate order of increasing *trans*-directing effect is as follows :

$$H_2O < OH < NH_3 \sim R{\cdot}NH_2 < \text{pyridine} < Cl < Br < CNS \sim I$$
$$\sim NO_2 \sim SO_3H \sim PR_3 \sim R_2S \sim SC(NH_2)_2 < NO \sim CO \sim C_2H_4 \sim CN$$

The groups at the CN end of this series are said to have a high *trans*-influence or high *trans*-effect and the general phenomenon of these directing effects is known as the *trans*-effect. The exact order of substituents in the series is not known with certainty; *e.g.*, a recent semiquantitative study by Hel'man and Karandashova [*Doklady Akad. Nauk S.S.S.R.*, 1952, **87**, (**4**), 597] places CN in the position occupied by the nitro-group in the above series and the latter between Cl and Br.

The way in which a ligand exerts its directing influence is unknown, but it has been generally assumed that groups of high *trans*-directing effect weaken the bond in the *trans*-position to themselves, *i.e.*, increase the tendency of that bond to heterolytic fission. This belief is so strongly held that Quagliano and Schubert (*loc. cit.*) use it to define the *trans*-effect : " The *trans*-effect stipulates that the bond holding a group *trans* to an electronegative or other labilising group is weakened." There is, however, no unequivocal evidence of a general weakening of the bond in the *trans*-position to a group of high *trans*-effect; we now find evidence that, in certain circumstances to be described, the bond may be strengthened. We prefer to define the *trans*-effect as follows : " The *trans*-effect or *trans*-influence of a group (A) co-ordinated to a metal ion is the tendency of that group to direct an incoming substituting group into the *trans*-position to itself (A)." Chemists of the Russian school refer to the labilisation of the *trans*-group by A, which does not necessarily mean that the bond in *trans*-position to A is weakened, although it is usually assumed. In discussing a co-ordinate bond, " bond weakening " means increasing tendency for the ligand-to-metal bond to break so that the ligand carries away with it the bonding electrons as a lone pair, *i.e.*, increasing tendency of the bond to heterolytic fission.

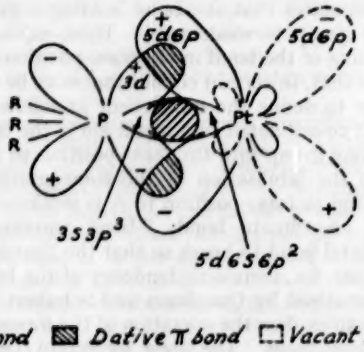
Various hypotheses, summarised by Quagliano and Schubert (*loc. cit.*), have been put forward by Russian chemists to explain the operation of the *trans*-effect but all assume and explain a weakening of the *trans*-bond. The latest, by Syrkin (*Izvest Akad. Nauk S.S.S.R., Otdel. Khim. Nauk*, 1948, 69), serves as a useful mnemonic for deciding the position of substitution in a platinous complex.

Chatt (*J.*, 1949, 3340) suggested that many more donor atoms than had previously been supposed might be bound to the later transition metals of each period, and especially to platinum(II), by bonds of partial double-bond character; also that there might be some direct correlation between the tendency of a ligand to bind by a double bond and the magnitude of its *trans*-effect (*Nature*, 1950, **165**, 637; Chatt and Williams, *J.*, 1951, 3061). The existence of such double bonding is now generally recognised (for summary of the present position see Craig *et al.*, *J.*, 1954, 332; Jaffé, *J. Phys. Chem.*, 1954, **58**, 185). In this paper we shall put forward a development of the idea that the amount of double bonding between a metal and a ligand through inductive and mesomeric effects is the main cause of the *trans*-effect, and the consequences of this hypothesis. Syrkin's hypothesis relegates double bonding to a subsidiary position in its relation to the *trans*-effect, which he supposes to be due primarily to a change in hybridisation of the σ-bonds.

The σ- and π-components of a double bond binding a ligand to a suitable transition metal may be visualised as follows. The σ-bond is formed by donation of a lone pair of electrons from the donor atom or group to the metal. The π-type bond (dative π-bond) is formed by the overlap of a filled *d*- or *dp*-hydrid orbital of the metal and a vacant *p*-, *d*-, or *dp*-hybrid orbital of the donor. The specific example of a C_2H_4–Pt bond where the dative π-bond is an essential part of the co-ordinate bond is shown schematically by Chatt and Duncanson (*J.*, 1953, 2939). In the case of the R_3P–Pt bond a similar schematic representation is given in Fig. 1, which also shows the vacant non-bonding *dp*-hybrid of the platinum atom.

Origin of the Force causing the trans-*Effect.*—In co-ordinate double bonds there can arise much greater inductive and mesomeric effects than are found in aromatic compounds. In theory the σ-bond may range from a strong bond with complete sharing of the lone pair and transfer of one electronic charge to the acceptor metal atom, to a weak bond with little transfer of charge (*e.g.*, in H_3BCO) and still further to no bond at all and no charge transfer. In fact the upper limit of charge transfer of single co-ordinate bonds between electrically neutral molecules or atoms appears to be about 0·65*e* (Phillips, Hunter, and Sutton, *J.*, 1945, 146). Also, since the lower limit of zero is only attained when there is no bond at all between the ligand and metal, the stable and very dipolar co-ordinate bonds which exist in the common platinous complexes must have strong σ-components (see Jensen, *Z. anorg. Chem.*, 1935, **225**, 97; 1936, **229**, 225; 1937, **231**, 365; Chatt and Wilkins, *J.*, 1952, 4300). It is to be expected, therefore, that the actual range in electrical asymmetries of co-ordinate σ-bonds in stable platinous complexes will be very much more limited than that theoretically attainable. Nevertheless, it is probably comparable with, or somewhat greater than, that found in organic compounds. On the other hand, the transfer of charge involved in dative

FIG. 1. *Schematic representation of the* $R_3P \rightarrow Pt$ *bond.*



π-bonding, which also has a theoretical range from zero to 1 *e* per π-type bond, is not so severely limited in practice. The lower limit of zero is attainable in such bonds as R_3N–Pt where the donor atom (N) has no vacant orbitals in its valency shell for dative π-bond formation. The upper limit is probably attained in such bonds as F_3P=Pt and OC=Pt which are almost non-polar (Chatt and Williams, *J.*, 1951, 3061). In these compounds the donation of electrons in the σ-bond is almost equal to the back donation in forming the π-type bond.

From such considerations as these it seems fairly certain that the range of magnitudes of inductive effects of donor atoms is not likely to be much greater in most robust complexes than in organic compounds. On the other hand, the range of mesomeric effects arising from the strength of dative π-bonding is probably so great that it may cover all gradations in net charge transfer from zero to 0·5*e* from metal to donor atom. There is thus a great range in the possible magnitude of the electron drift in π-type orbitals from the metal to donor atom. It is this and the rectilinear symmetry of the *d*-orbitals which we consider to be mainly responsible for the directing forces found in square planar and octahedrally co-ordinated complex compounds. The greater the electron drift in π-type orbitals towards the ligand A, the greater the strength of double bonding, A=Pt, and the greater the *trans*-effect of A.

It should be emphasised, however, that, although the above treatment gives some idea of the magnitude of the range of electrical effects associated with co-ordination by double-bonded ligands, it is not intended to imply that the dative σ- and π-bonds are independent. On the contrary, since one tends to neutralise the electrostatic effects of the other they will

enhance each other, increasing together without effect on the net charge transfer, but strengthening the double bond.

Transmission of the Directing Forces across the Metal Atom.—As we have shown, ligands in complex compounds should exhibit strong inductive and mesomeric effects; however, the inductive effect, being largely electrostatic in character, should affect all the other ligands (B) attached to the same metal atom in a similar manner. On the other hand, the mesomeric effect would influence almost entirely the *trans*-position, just as in benzene chemistry it affects the *ortho*- and *para*-positions preferentially. Fig. 2 showing the ligand A bound by $p_\pi - d_\pi$ dative π-bonding illustrates how this occurs. The d_{xz} orbital stretches right across the atom, and so the electron withdrawal into the regions of the dative π-bond *aa'* will reduce the electron density in the antinodes *bb'* in *trans*-positions to *aa'*. If the ligand B in *trans*-position to A has an unfilled π-type orbital capable of dative π-bonding with *bb'* it enters into direct competition with the ligand A for *d*-electrons. Thus the strength of dative π-bonding at B is considerably reduced from what it would be if A were a ligand with little or no double-bonding properties. In this way strong double bonding of the metal to A leads to weak double bonding to B in the *trans*-position. The ligands in *cis*-positions relative to A are, however, only slightly influenced because the

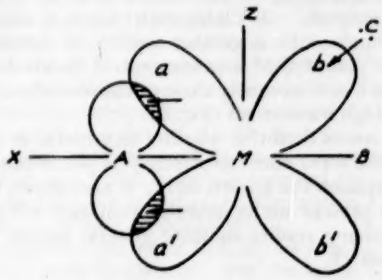


FIG. 2. *Electron withdrawal by the ligand* A *from a* d*-orbital of the metal* M *on forming a dative* π*-bond, and proposed mechanism of substitution of* B *by a donor* C *in presence of a ligand* A *of high* trans*-effect.*

d_{xy} and d_{yz} orbitals, at right angles to A–M–B, are affected only by the electrostatic effect of electron withdrawal by A, and this equally affects B.

Mechanism of the trans*-Effect.*—Current theory assumes that the *trans*-effect operates by the weakening of the bond in *trans*-position to a ligand A of high *trans*-effect. However, the double-bonding hypothesis leads to the deduction that *trans*-bond weakening will only occur if the *trans*-group, B, also has a high *trans*-effect. In fact, a group A of high *trans*-effect facilitates the replacement of the *trans*-group, B, whether it (B) has a low or high *trans*-effect and so the double-bonding hypothesis and assumption of universal bond weakening are incompatible. A mechanism which fits the facts better than that of *trans*-bond weakening is however available.

If all the groups attached to the metal atom have a low *trans*-effect, the withdrawal of *d*-electrons to form dative π-bonds will be small and the electron density in the *d*-orbitals of the metal will be high, thus discouraging nucleophilic attack at the *d*-orbitals. It must be emphasised that all substituting reagents in complex chemistry are nucleophilic. The slow displacement reaction may therefore occur by slow S_N1 dissociative or S_N2 associative mechanism. However, if one of the ligands is replaced by a ligand of high double-bonding capacity the *d*-electron withdrawal from the metal atom will increase its electron affinity. Evidence of this increased electron affinity in the platinous series of complexes is provided by the resistance to oxidation shown by platinous complexes containing groups of high *trans*-effect; *e.g.*, $K[C_2H_4PtCl_3]$ shows the same resistance to oxidation as $K[NH_3PtCl_5]$ (Hel'man and Ryabchikov, *Compt. rend. Acad. Sci., U.R.S.S.*, 1941, **33**, 462) and $(CO)_2PtCl_2$ is prepared in presence of chlorine. The increase in electron affinity will facilitate nucleophilic attack and so accelerate an S_N2 reaction. Also, since the electron withdrawal occurs particularly from the regions *bb'*, it facilitates the introduction of groups to the side of the molecule remote from the group A, and near to the *trans*-group B, which may then be

eliminated and replaced by the substituting group C (Fig. 2). The greater the double-bonding properties of A the greater the electron affinity of the metal atom, especially in the regions *bb'*, and the faster the rate of substitution. In this way the double-bonding hypothesis predicts that the slow substitutions characteristic of *cis*-substitution may be S_N1 or S_N2 reactions, but the fast substitutions occurring in complex compounds containing a group of high *trans*-effect should be of S_N2 type and the greater speed of *trans*-substitution would be due to a lowering of the activation energy of formation of the transition state, rather than to a weakening of the *trans*-bond.*

The fact that the *trans*-effect was first noticed in platinous complexes rather than in those of other metals is not fortuitous, because electronic conditions in platinous complexes are especially favourable to the development of directing effects by the mechanism just outlined. These favourable conditions are that: (1) Double bonding is facilitated in the last transition series where the 5*d*-orbitals have energy levels close to the 6*s* and 6*p* (distinction from palladium and nickel). (2) The vacant $6p_z$-orbital of the platinum atom, by hybridisation with the $5d_{z^2}$-orbital, produces π-type orbitals especially favourable for dative π-bond formation (see Fig. 1) (Craig *et al.*, *loc. cit.*). When one of these is involved in dative π-bond formation, the other, in much the same place as the antinodes *bb'* of the pure *d*-orbital (Fig. 2), is available to receive the lone electron pair of the attacking nucleophilic reagent. (3) Platinum(II) forms a unique series of configurationally stable complex compounds with a greater variety of ligands than any other acceptor atom. (4) The square planar dsp^2 arrangement of bonds brings the substituting ligand entering in the regions *b* or *b'* uniquely close to the *trans*-ligand B, causing 100% *trans*-substitution when A has a high *trans*-effect (Fig. 2).

It seems doubtful whether any metal in a common valency state, except gold(III), will show the *trans*-effect so strongly as platinum(II). The double-bonding hypothesis is simple and explains the known facts; it also allows the prediction of effects undiscovered. These are at present under investigation and will be described in subsequent communications; preliminary results indicate general accord with the double bonding hypothesis of the *trans*-effect.

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THE FRYTHE, WELWYN, HERTS. [*Received, June 13th*, 1955.]

* *Note added 24th June*, 1955.—Zvyagintsev and Karandasheva (*Doklady Akad. Nauk S.S.S.R.*, 1955, **101**, 93) have just published the results of a kinetic study of the reaction of pyridine with a series of compounds of the type $K[NH_3PtXYZ]$, where X, Y, and Z are halogens or nitro-groups; X is the group replaced under the *trans*-influence of Z, and both of these groups are in *cis*-positions relative to NH_3. They find that the reaction has second-order kinetics. As the rate constant increases, indicating increasing *trans*-effect of Z, the activation energy of the substitution decreases; this is in accord with our hypothesis.

Directing Effects in Inorganic Substitution Reactions. Part II. An Infrared Spectroscopic Investigation of the Inductive Effects of a Variety of Uncharged Ligands in Complex Compounds of Platinum*(II).

By J. Chatt, L. A. Duncanson, and L. M. Venanzi.

[Reprint Order No. 6501.]

The infrared spectra of a series of complex compounds of the type *trans*-[L,amPtCl$_2$] were examined in carbon tetrachloride solution. In these compounds "am" is a primary or secondary amine, especially *p*-toluidine and piperidine, and L a series of ligands, piperidine, 4-*n*-alkylpyridine, PR_3, AsR_3, SbR_3, R_2S, R_2Se, R_2Te, $P(OR)_3$, and C_2H_4 (R = *n*-alkyl). The complex compounds containing primary amines associate by hydrogen bonding. The N–H stretching frequencies of the monomeric complexes were measured, and also the band intensities of the piperidine complexes and bimolecular association constants of the *p*-toluidine complexes (Table 1). The differences in these properties from one complex to another are interpreted in terms of changes in electron distribution in the L–Pt–N–H bonds. Strong inductive effects are transmitted across the platinum atom from the ligands L to the N–H bond, and the donor capacities of the various donor atoms are correlated with their electronegativities. Nitrogen is certainly the poorest and phosphorus about the best donor to platinum(II). Certain irregularities are attributed to the transmission of slight but significant mesomeric effects. By using these peculiarities the ligands have been arranged in a series: 4-*n*-alkylpyridine, piperidine, R_2S, R_2Se, R_2Te, AsR_3, PR_3, SbR_3, $P(OR)_3$, and C_2H_4, such that all the measured properties run in similar sequence. This order is determined by electronegativity from piperidine to R_2Te, but from AsR_3 to C_2H_4 the order is probably that of increasing tendency to co-ordinate by double bonds.

The investigation shows that the *trans*-directing effect of a ligand is not directly related to its inductive effect or electronegativity; also the *trans*-effect does not operate by *trans*-bond weakening (*i.e.*, by increasing the tendency to heterolytic fission of the bond in *trans*-position to the ligand, L). This is evidence against a dissociative (S_N1) mechanism of *trans*-directed substitution, but it is consistent with the "double bonding hypothesis" which is discussed in Part I.*

In Part I* we discussed the phenomena of directing effects in the substitution reactions of inorganic complex ions and presented a new hypothesis as to their origin. In one very important particular that hypothesis conflicted with the currently accepted theory, which supposes that ligands which direct incoming groups into the *trans*-position to themselves in complex-ion substitution reactions do so by weakening the bond in *trans*-position to themselves (for references see Part I). "Bond weakening" in this context and throughout this communication means a greater tendency of the ligand-to-metal bond to undergo heterolytic fission, the ligand carrying away the bonding electrons. For example in the system L–M–B, where L and B are ligands in *trans*-positions about the metal M, current theory requires that the greater the *trans*-directing effect of L the greater the electron drift in the bond M–B towards the group B, and the greater the tendency for B to separate with its bonding electrons. Such an explanation of the operation of the *trans*-effect also implies that *trans*-substitution occurs by an S_N1 mechanism.

The experiments described in this communication were designed to investigate the distribution of electrons in the M–B bond under the influence of various groups L. For this purpose it was essential that the M–B bond should be a single bond or nearly so: hence amines were chosen as B. Platinum(II) was chosen as the metal because it is only in relation to platinum(II) that there is any great volume of existing knowledge about directing effects in inorganic complexes. The nature of the ligands, L, was determined mainly by the ease with which a series of suitable compounds could be synthesised. This

* Part I, preceding paper.

was achieved by making L a series of uncharged ligands having as great a variety of donor atoms as possible; ethylene, amines, and the *n*-alkyl derivatives $P(OR)_3$, PR_3, AsR_3, SbR_3, R_2S, R_2Se, and R_2Te were used. Little is known with certainty of the *trans*-directing effects of these ligands except that amines are the most strongly *cis*-directing and ethylene the most strongly *trans*-directing [see Chatt and Williams, *J.*, 1951, 3061; Hel'man and Karandashova, *Doklady Akad. Nauk S.S.S.R.*, 1952, **87**, (4), 597]. Work now in progress also indicates that the *trans*-directing effects of organic phosphines are greater than those of sulphides and selenides (see Ahrland and Chatt, *Chem. and Ind.*, 1955, 96).

The series of compounds actually examined were of the type *trans*-[L, am$PtCl_2$] where " am " is a primary or secondary amine. The problem thus resolves itself into finding the change in electron distribution in the Pt–N bond from one compound to another in the above series. It was solved by measuring the N–H stretching frequencies (ν_{N-H}) by observation of the infrared spectra of the above series of compounds in dilute carbon tetrachloride solution. In the piperidine series the band intensities were also measured. The sizes of the alkyl groups, R, were chosen so as to render the complexes containing them sufficiently soluble in carbon tetrachloride for this investigation.

It was found that most of the complexes containing primary amines are associated in carbon tetrachloride solution by intermolecular hydrogen bonding through the N–H bonds. The degree of association depends on the ligand represented by L. The nature of the association and a detailed description of typical spectra will be given in another communication (for a preliminary note see Chatt, Duncanson, and Venanzi, *Atti Accad. naz. Lincei, Rend. Classe Sci. fis. mat. nat.*, 1954, **17**, 120) but the approximate association constants, $K_{ass.}$, for bimolecular association are relevant to the present discussion. These and the spectroscopic data are listed in the Tables.

In Tables 1(*A*) and 1(*C*) the ligands, L, are the only variables and are listed in increasing order of electronegativity. It is difficult to place ethylene in this series, because it does not contain a donor atom with a lone pair of electrons; nevertheless, there seems little doubt that its correct position is near the nitrogen end of the series. The first ionisation potential of the π-electrons is 10·5 ev (Price and Tutte, *Proc. Roy. Soc.*, 1940, *A*, **174**, 207), about the same as that of the lone pair of ammonia, 10·8 ev, and higher than those of the common amines, 9·6 ev (Sugden, Walsh, and Price, *Nature*, 1941, **148**, 372; Price and Walsh, *Proc. Roy. Soc.*, 1947, *A*, **191**, 22), which suggests that ethylene might occupy a position even lower in the tables than the amines. On the other hand, carbon has about the same electronegativity as sulphur and so ethylene has been placed tentatively between the amines and sulphides.

Independently of any interpretation of the spectroscopic data the following conclusions can be drawn from the measurements listed in the Tables.

(1) The sizes of the alkyl groups, R, in the ligands, L, do not affect the N–H stretching frequencies within the limits of experimental error, *e.g.*, see the homologous series *trans*-[PR_3,*p*-$CH_3{\cdot}C_6H_4{\cdot}NH_2$,$PtCl_2$] (R = Et, Pr^n, and Bu^n) in Table 1(*C*). Evidently the large mass of the platinum atom effectively insulates the co-ordinated amines so that their high-frequency modes of vibration are independent of the masses and shapes of the various ligands L.

(2) The frequencies decrease and intensities increase with increasing electronegativity of L [Tables 1(*A*) and 1(*C*)]. Ethylene and ligands containing phosphorus do not quite fit into their places in the sequence, but nevertheless the correlation between the electronegativities of L and the spectroscopic data is sufficiently good to show that the effects of the ligands, L, on the N–H bonds are in the main inductive.

(3) Although the different ligands, L, produce definite changes in the N–H stretching frequencies [Tables 1(*A*) and 1(*C*)], the groups, X, in *trans*-[PPr^n_3,*p*-$X{\cdot}C_6H_4{\cdot}NH_2$,$PtCl_2$] [Table 1(*D*)] have negligible effect throughout the series, X = H, CH_3, C_6H_5, Cl, NO_2, and OCH_3. Evidently the electrical effects which influence the N–H bonds and are transmitted across the platinum atom are much stronger than those transmitted across the aromatic nucleus. The quaternary nitrogen atom, like the saturated carbon atom, would not be expected to transmit mesomeric effects, except perhaps rather weakly by hyperconjugation; and the absence of any dependence of the N–H frequencies on X is evidence of this.

(4) Although the N–H frequencies are insensitive to a change in X they are very sensitive to changes in small hydrocarbon groups attached to the nitrogen atom. In these circumstances the inductive, steric, and mass effects of the small groups are all able to exert their influence directly on the nitrogen atom and changes of up to 35 cm.$^{-1}$ are observed {*e.g.*, compare *trans*-[PPr^n_3,Et_2NH,$PtCl_2$] and *trans*-[PPr^n_3,MePhNH,$PtCl_2$] in Table 1(*B*)}.

TABLE 1. *The* N–H *frequencies* ν (*cm.*$^{-1}$), *band intensities* B (*cm.*$^{-2}$ *molecules sec.*$^{-1}$), *and association constants*, $K_{ass.}$, *for the compounds* trans-[L,amPtCl_2] *at* 25°.

(*A*) " am " = Piperidine.

L	ν_{N-H} (± 1)	10^7B (± 2·5%)	L	ν_{N-H} (± 1)	10^7B (± 2·5%)
$SbEt_3$	3235	—	Et_2S	3223	1·66
$AsPr^n_3$	3232	1·41	C_5H_4	3230	1·59
PPr^n_3	3237	1·35	Piperidine	3222	3·36 *
$P(OMe)_3$	3233	1·43	4-*n*-Pentylpyridine	3217	1·82
Et_2Te	3230	1·49	(*Cf.* also free piperidine †)	3350	~0·1
Et_2Se	3224·5	1·60			

* This figure must be halved for comparison with the others since the complex contains two independent but identical N–H groups.

† Russell and Thompson, *J.*, 1955, 483.

(*B*) " am " = Other secondary amines.

L	" am "	ν_{N-H} (±1)	L	" am "	ν_{N-H} (±1)	L	" am "	ν_{N-H} (±1)
PPr^n_3	Diethylamine	3237	PPr^n_3	*N*-Methylaniline	3261	C_5H_4	Dimethylamine	3261

(*C*) " am " = *p*-Toluidine

L	$\nu_{asym.}$ (±1)	$\nu_{sym.}$ (±1)	$K_{ass.}$ (±10%)
$SbPr^n_3$	3346	3275	40
$AsPr^n_3$	3342	3271	24
PEt_3	3347	3277	18
PPr^n_3	3348	3277	18
PBu^n_3	3348	3276	15
$P(OEt)_3$	3344	3275	—
Pr^n_2Te	3337	3270	—
Pr^n_2Se	3330	3264	—
Pr^n_2S	3329	3262	77
Bu^n_2S	3328	3263	77
C_5H_4	3331	3265	115
Cf. also *trans*-[PPr^n_3,*p*-$CH_3{\cdot}C_6H_4{\cdot}NH_2$,$PtCl_4$]	3330	3268	—
trans-[PPr^n_3,*p*-$CH_3{\cdot}C_6H_4{\cdot}NH_2$,$PdCl_2$]	3365	3291	2
Free *p*-toluidine	3471	3390	—

(*D*) " am " = Other primary amines

L	" am "	$\nu_{asym.}$ (±1)	$\nu_{sym.}$ (±1)
PPr^n_3	Methylamine	3347	3284
PEt_3	Ethylamine	3336	3271
PPr^n_3	Benzylamine	3332	3268
PPr^n_3	Aniline	3347	3277
PPr^n_3	*p*-Phenylaniline	3345	3275
PPr^n_3	*p*-Chloroaniline	3346	3274
PPr^n_3	*p*-Nitroaniline	3348	3276
PPr^n_3	*p*-Anisidine	3347	3277
PPr^n_3	2 : 6-Dimethylaniline	3346	3267
Bu^n_2S	2 : 6-Dimethylaniline	3329	3249
C_5H_4	2 : 6-Dimethylaniline	3324	3253
4-*n*-Nonylpyridine	2 : 6-Dimethylaniline	3268	3199
C_5H_4	Methylamine	3334	3277
C_5H_4	Ethylamine	3324	3263

(5) The association constants, $K_{ass.}$, show little correlation with the other properties tabulated in Table 1(*C*).

Interpretation of the Spectroscopic Data in Terms of the Electron Distribution in the L–Pt–N–H *Bonds.* All the spectroscopic data concern the N–H bonds and so must be interpreted in terms of electron distribution in the Pt–N bond to obtain information relevant to the operation of the *trans*-effect.

The change in intensity of the N–H band with change in electron distribution in the Pt–N bond is not easily predictable. Russell and Thompson (*loc. cit.*) have found, however,

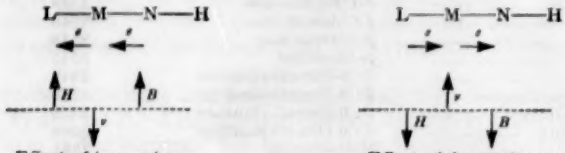
that the intensities of the fundamental N–H stretching bands of secondary amines increase with the acidity of the N–H groups, and so increasing intensity corresponds to increasing positive charge on the nitrogen atom.

The factors affecting the N–H stretching frequencies of amines have been investigated by Richards (*Trans. Faraday Soc.*, 1948, **44**, 40), Flett (*ibid.*, p. 767), and Fuson *et al.* (*J. Chem. Phys.*, 1952, **20**, 145). The results of these investigations are not directly applicable to our problem because in the free amines the hybridisation of the nitrogen atom may, in theory, vary from p^3 to sp^3, and sp^2. However, the above work, and that of Linnett (*Trans. Faraday Soc.*, 1945, **41**, 223; see also Longuet-Higgins, *ibid.*, p. 233) leads to the general conclusion that, for a given N–H bond type, increasing negative charge on the nitrogen atom increases the force constant of the N–H bond and decreases the acidity of the amine. Large changes in bond type are not likely in our complexes; with four groups attached to the nitrogen atom, its hybridisation must always approximate to sp^3, and so the above generalisation should apply. It is known that only small changes in hybridisation of the tetrahedral carbon atom are caused even by very large changes in electronegativities of the groups attached (*e.g.*, Allen and Sutton, *Acta Cryst.*, 1950, **3**, 46).

We have two pieces of supporting evidence from complex chemistry that the generalisation does apply. (*a*) In *trans*-[PPr^n_3,*p*-$CH_3{\cdot}C_6H_4{\cdot}NH_2$,$PtCl_4$], where the metal is more positively charged than in its platinous analogue, the greater electron affinity of the metal causes a decrease of some 13 cm.$^{-1}$ in the N–H stretching frequencies [see Table 1(*C*)]. (*b*) Palladous complexes have the same general electronic structure as their platinous analogues but are as a rule less stable. Rightly or wrongly, this fact has commonly been interpreted as an indication that the electron-acceptor properties of palladium(II) are not so great as those of platinum(II). In agreement with this view we now find that the N–H stretching frequencies of *trans*-[PPr^n_3,*p*-$CH_3{\cdot}C_6H_4{\cdot}NH_2$,$PdCl_2$] are some 12 cm.$^{-1}$ higher than those of its platinous analogue. The lower acidity of the *N*-hydrogen atoms in the palladous than in the platinous complex is also evident from its low association constant [see Table 1(*C*)].

A weakening of the Pt–N bond, *i.e.*, a displacement of the bonding electrons from the platinum atom towards the nitrogen atom, would cause the nitrogen atom to become more negatively charged. The above evidence indicates that such a change would be accompanied by an increase in N–H stretching frequency and a decrease in band intensity. Our experimental data interpreted according to this scheme give a very simple general picture of the electron drifts in the L–Pt–N–H bond system as follows:

The least electronegative ligands, L, by donating their electrons more completely to the metal atom, M, cause it in turn to release electrons to the nitrogen atom. This as a consequence binds its hydrogen atoms more firmly and increases its N–H stretching frequency. These relations between electron drifts (*e*), M–N bond strength (*H*) and spectroscopic data (frequency, ν, and intensity, *B*) are summarised in the following diagram.*



Although this scheme is essentially correct as shown by the correlation between electronegativities of the donor atoms in L and the observed N–H frequencies, it is not yet complete. It does not explain the slightly anomalous positions of the phosphorus-containing ligands and ethylene.

Complexes containing phosphorus have higher N–H frequencies than those of the other members of the phosphorus triad, and not lower ones as would be expected from the electronegativity of phosphorus. Also, ethylene gives complexes with greater N–H frequencies

* The authors thank a Referee for suggesting the inclusion of this diagram.

than would be expected. We must conclude that there is a factor which influences the N–H frequencies, and is not inductive. This factor apparently raises the N–H frequencies above the values to be expected empirically on the basis of the electronegativities of the donor atoms in the ligands, L. It does not appear to be significant except in the ethylene- and phosphorus-containing complexes. Consequently, if the ligands, L, are arranged in order of decreasing N–H frequencies of their complexes, *trans*-[L,amPtCl$_2$] [*i.e.*, PR_3 > SbR_3 > $P(OR)_3$ > AsR_3 > R_2Te > C_2H_4 > R_2Se > R_2S > Piperidine > 4-*n*-Pentylpyridine] the order must be close to that of increasing strength of the Pt–N bonds, and of

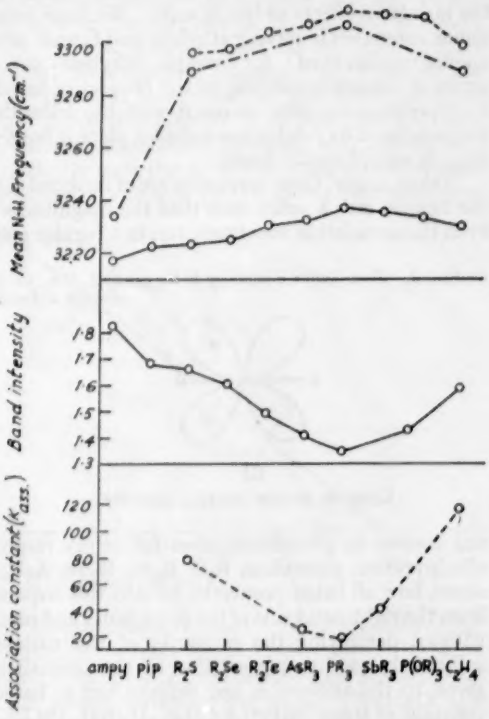


FIG. 1. *Plots of spectroscopic data and association constants against the unique order of ligands* " ampy " * *to* C_2H_4.

* " ampy " = 4-*n*-Pentylpyridine.
" pip " = Piperidine.

— — — *p*-Toluidine complexes.
——— Piperidine complexes.
– · — · – 2 : 6-Dimethylaniline complexes.

decreasing tendency of L to donate electrons to platinum. Two interesting conclusions may be drawn :

(1) If previous investigators are correct in supposing that ethylene has the greatest *trans*-directing effect of the uncharged ligands in the above series (see Part I, *loc. cit.*), the *trans*-effect cannot operate by *trans*-bond weakening, because this implies that the ethylene complexes have the weakest Pt–N bonds. The strength of the Pt–N bond in the ethylene complexes appears to be slightly greater than that of the telluride complexes. It may be even greater than its position in the above series indicates, because the unknown factor has the effect of placing ethylene too high in the series. Certainly, the olefin complexes do not contain the weakest Pt–N bonds.

(2) The completeness of donation of electrons to platinum from widely different donor atoms which occurs in the various ligands, L, does not determine the qualitatively observed general stabilities of their complexes. The latter may be classified as : very stable (L = PR_3 and R_2S), stable (L = AsR_3 and amines), and rather unstable (L = C_2H_4, SbR_3, R_2Te, and R_2Se). This series bears no relation to the above sequence of decreasing donor capacities of the ligands, L.

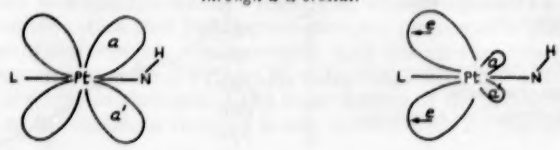
The relationship between the positions of the donor atoms in the Periodic Table and the

stabilities of their platinous complexes is very interesting and shows an inversion between the fifth and the seventh group of donor atoms in the Periodic Table. In the fifth group it runs $NR_3 \ll PR_3 > AsR_3 > SbR_3 > BiR_3$ (Chatt, *J.*, 1951, 652). In the sixth group it is $R_2O \ll R_2S \gg R_2Se < R_2Te$ (Chatt and Venanzi, *J.*, 1955, 2787), and in the seventh group $F^- \ll Cl^- < Br^- < I^-$ (Leden and Chatt, *J.*, 1955, 2936). Platinous complexes with tertiary bismuthines, ethers, or the fluoride ion co-ordinated to platinum(II) are unknown.

Arrangement of Ligands in a Series according to Their Inductive and Mesomeric Effects.— So far we have considered in detail only the N–H frequencies and band intensities and have shown that the differences caused by changing the ligands, L, are due almost entirely to the inductive effects of the ligands. We have also drawn attention to two obvious though minor anomalies involving ethylene and ligands containing phosphorus. Other less obvious anomalies also exist; for example, ethylene cannot be fitted into any definite place in the series of ligands according to the properties listed in the tables. The N–H frequency of its piperidine complex places it with the tellurides, but its band intensity and the N–H frequencies of its *p*-toluidine complex place it beside the selenides. Its association constant, $K_{ass.}$, is exceptionally large.

Taken singly, these anomalies are of doubtful significance. Together they allow us to sort the ligands into a series such that the magnitudes of all the properties listed in the tables, even the association constants, run in a regular and similar manner. They rise or fall from

FIG. 2. *How dative π-bonding to the group* L (*i.e., its mesomeric effect*) *may influence the* N–H *bond through a* d-*orbital.*



(I) L has no double-bonding capacity.

(II) L forms a strong dative π-bond.

the amines to phosphines, then fall or rise respectively to ethylene. The series is: 4-*n*-alkylpyridine, piperidine, R_2S, R_2Se, R_2Te, AsR_3, PR_3, SbR_3, $P(OR)_3$, and C_2H_4. Fig. 1 shows how all listed properties fit into this sequence. It is not possible to take any ligand from the right-hand side of the phosphines and place it in a definite position on the other side without destroying the similarity of the various graphs in Fig 1. The correlation is sufficiently good to suggest that all the anomalies have one ultimate cause. The position given to the stibines is not definite but is based solely on the value of the association constant of *trans*-[$SbPr^n_3$,*p*-$CH_3{\cdot}C_6H_4{\cdot}NH_2$,$PtCl_2$].

The significance of the sequence seems clear. The ligands to the left of the phosphines exert their influence on all the properties we have measured, mainly through induction in the L–Pt bond.

Phosphines and those ligands to the right of the phosphines have imposed on the inductive effect the other factor which causes a slight irregularity. Since the phosphites and olefins are the most strongly double-bonding ligands in this series the anomaly is most probably caused by their mesomeric effects. Thus we have our most electronegative ligands to the left, and most strongly double-bonding to the right, of phosphorus in the sequence. To the left of phosphorus the ligands are in order of increasing electronegativity; to the right, probably of increasing tendency to form dative π-bonds.

There are two obvious interdependent ways in which the mesomeric effect resulting from the formation of a dative π-bond by the ligand, L, can affect the N–H vibration. (*a*) The increase in electron affinity of the platinum atom caused by the drift of electrons from its *d*-orbitals into the dative π-bond will strengthen the Pt–N bond and so decrease the N–H frequency. (*b*) The drift of electrons from the metal atom in the dative π-bond towards the ligand, L, will decrease the electron affinity of the donor group. This will enhance the donation of its lone pair in the L–Pt σ-bond, and so in turn reduce the electron

affinity of the platinum atom. This will result in a weakening of the Pt–N bond and so increase the N–H frequency.

Doubtless both of these effects occur, and if they were the only factors, the effect of (*b*) must outweigh that of (*a*), but our observations cannot be accommodated on that basis alone; to obtain a complete explanation it is necessary to assume that there is some direct interaction between the N–H group and the *d*-orbitals of the platinum atom. One may picture such interaction as in Fig. 2, the interaction occurring between the N–H group and the antinodes, *aa'*, of a *d*-orbital; our evidence that it occurs is as follows:

In the piperidine complexes, with the single exception of the ethylene complex, we find empirically that there is a linear relation between the square-root of the band intensity and the N–H stretching frequency (Fig. 3). The band intensity of the ethylene complex is significantly greater than would be predicted from the N–H frequency, according to this linear relation. If the only factor affecting the N–H bond were the position of electrons in the Pt–N bond, as required by (*a*) and (*b*) above, it is difficult to see how that one cause could produce at one N–H frequency two different intensities. However, if the N–H bond is affected by L in two ways, both inductively through the Pt–N bond and mesomerically through weak interaction of the *d*-orbital with the proton or N–H bonding electrons, then

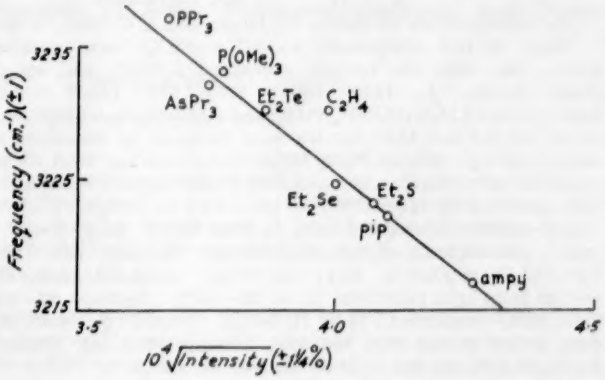


FIG. 3. *Plot of* N–H *frequency against the square-root of the band intensity of the complexes,* trans-[L, pip, $PtCl_2$].*

* "ampy" = 4-*n*-Pentylpyridine.
"pip" = Piperidine.

The "errors" define the limit of reproducibility.

these two ways may influence the N–H frequencies and band intensities differently. Different combinations of inductive and mesomeric effects might thus result in the same N–H frequency, but different band intensities, as happens, *e.g.*, in the telluride and ethylene complexes. It may be significant that the points corresponding to the phosphite and phosphine complexes in Fig. 3 are slightly displaced to the same side of the line as the point corresponding to the ethylene complex.

The interaction between the N–H group and the *d*-orbitals of the platinum atom may occur either (*a*) by the interaction of the N–H bonding electrons with the vacant *dp*-hybrid, when L is strongly double bonding—a type of hyperconjugation—or (*b*) by the interaction of the proton with electrons in a filled *d*-orbital—a type of intramolecular hydrogen bonding. Further work with metals other than platinum(II) is in hand to determine the exact nature of the interaction, but preliminary results favour (*b*). Such interaction of the *N*-hydrogen atoms with filled *d*-orbitals may be a significant contributory cause of the low stability of tertiary alkylamine complexes of the transition metals, as compared with their ammines and primary and secondary amine complexes (*e.g.*, see Chatt and Wilkins, *J.*, 1952, 4300).

The rapid rise in the association constants of the complexes containing ligands to the right of the phosphines in our series may also be explained on the basis of electron withdrawal from the *d*-orbitals of the metal by L when it forms a π-type bond. The complexes *trans*-[L,am$PtCl_2$] associate through intermolecular N–H· · · · Cl bonds. The formation of the hydrogen bond may be opposed by lone-pair repulsion between the *d*-electron pairs of the platinum atom and *p*-electron pairs of the chlorine atom, and also by interaction of the proton with the *d*-electrons. Association may thus be increased either by raising the

electronegativity of the ligand, L, and so enhancing the acidity of the NH_2-group, or by increasing the strength of dative π-bonding to L, and so diminishing the lone-pair repulsion and proton interaction (cf. Fig. 2). Ethylene is one of the more electronegative ligands and has the greatest tendency to form double bonds; we should therefore expect its complexes to have high association constants, as we have observed. The association may be subject to steric factors other than lone-pair repulsion. The greater association of the ethylene complex may be partly due to the small bulk of the ethylene molecule, which might favour the formation of the dimer. On the other hand, the bulk of the ligand, L, does not appear to be of prime importance since all the phosphine homologues have about the same association constants [Table 1(*C*)]. Certainly steric effects of the ligands, L, are not likely to account for the different tendencies of the tri-*n*-propyl-phosphine, -arsine, and -stibine complexes to associate.

A complete series of association constants could not be obtained because the compounds of the type *trans*-[am,*p*-$CH_3{\cdot}C_6H_4{\cdot}NH_2$,$PtCl_2$] (am = an amine) which we prepared were not soluble in carbon tetrachloride, and the selenide and telluride compounds, *e.g.*, *trans*-[Pr^n_2Te,*p*-$CH_3{\cdot}C_6H_4{\cdot}NH_2$,$PtCl_2$], were too unstable to be isolated.

Experimental

Microanalyses are by Messrs. W. Brown and A. G. Olney of these laboratories.

Most of the compounds *trans*-[L,amPtCl$_2$] were obtained by the reaction of the amine, am, with the bridged compound $L_2Pt_2Cl_4$ and are described in previous publications (Chatt, *J.*, **1950**, 2301; **1951**, 652; Chatt and Venanzi, *J.*, **1955**, 3858). *trans*-[Pr_2Se,*p*-$CH_3{\cdot}C_6H_4{\cdot}NH_2$,$PtCl_2$] and *trans*-[$Pr_2Te$,*p*-$CH_3{\cdot}C_6H_4{\cdot}NH_2$,$PtCl_2$] were too unstable to be isolated but their spectra were obtained by dissolving the appropriate solid bridged compound, *e.g.*, $(Pr_2Se)_2Pt_2Cl_4$ (*idem*, *ibid.*), together with its equivalent of solid *p*-toluidine in carbon tetrachloride and examining the spectrum of the solution. The following compounds were prepared by the reaction of the amine on K[$C_2H_4PtCl_3$] in the same general manner as their *p*-toluidine analogue (Chatt, *J.*, **1949**, 3340). trans-*Methylamine-ethylenedichloroplatinum*, yellow needles from carbon tetrachloride; decomp. 125—129° (Found: C, 11·1; H, 2·8. $C_3H_9NCl_2Pt$ requires C, 11·1; H, 2·8%). trans-*Ethylamine-ethylenedichloroplatinum*, yellow needles from light petroleum (b. p. 60—80°); decomp. 85—89° (Found: C, 14·9; H, 3·4. $C_4H_{11}NCl_2Pt$ requires C, 14·2; H, 3·3%). trans-2 : 6-*Dimethylaniline-ethylenedichloroplatinum*, deep yellow prisms from benzene; decomp. 150—155° (Found: C, 28·8; H, 3·7; N, 3·7. $C_{10}H_{15}NCl_2Pt$ requires C, 28·9; H, 3·6; N, 3·4%).

trans-*Dipiperidinedichloroplatinum*. The crude mixture of *cis*- and *trans*-bisdimethylsulphidedichloroplatinum (2 g.), prepared by reaction of dimethyl sulphide with aqueous K_2PtCl_4 (Enebuske, *J. praht. Chem.*, **1888**, **38**, 358), was suspended in dibutyl ether (50 c.c.); piperidine (0·5 c.c.) was added, and the mixture boiled under reflux for 15 min. The hot reaction mixture was filtered and the product separated in needles as the filtrate cooled. Recrystallised repeatedly from ethanol, the pure *complex* was obtained in 50% yield; decomp. 252—255° (Found: C, 27·6; H, 5·2. $C_{10}H_{22}N_2Cl_2Pt$ requires C, 27·5; H, 5·1%).

Spectra were measured at 25 ± 1° with a Grubb-Parsons S3A single-beam spectrometer fitted with a lithium fluoride prism. The 3μ ammonia and methane bands were used for frequency calibration, the accuracy of which was ±1 cm.$^{-1}$. The carbon tetrachloride used as solvent was distilled over phosphoric oxide and stored over solid potassium hydroxide before use. The intensities, *B*, of the N–H stretching bands of the piperidine complexes were found by measuring the optical density at the frequency of minimum transmission and the band width at half this optical density. These quantities were substituted in the equation,

$$B = K(\log_e T_0/T)\Delta\nu_{\frac{1}{2}}^{a}\,(\boldsymbol{N}cl)^{-1}$$

where T_0 and T are respectively the measured incident and transmitted intensities, $\Delta\nu_{\frac{1}{2}}^{a}$ is the apparent half band-width in cycles per second, $\boldsymbol{N}$ is Avogadro's number, c is the concentration in moles per c.c., l is the cell thickness in cm., and K is a factor related to the band shape and the spectral slit width as calculated by Ramsay (*J. Amer. Chem. Soc.*, **1952**, **74**, 72). The values of K were obtained from his table. T_0 was found by measuring the energy transmitted by the cell (1-cm., fused silica) containing pure solvent. This operation was repeated twice before and twice after the examination of each solution, and the mean value was taken as T_0. The N–H band of a given solution was measured five times to obtain mean values of the peak

height and half-width. This procedure was repeated for three different concentrations of each complex in the range 0·006—0·009 M, and the deviations from the mean value were found to be no greater than ±2·5%, usually being of the order of 1%. The limits of ±2·5% can be taken as the accuracy of the relative intensities, although the absolute accuracy may be less owing to uncertainty about the true spectral slit width, the estimated value of which was 4 cm.$^{-1}$. The apparent band half-widths of the N–H stretching bands in the complexes *trans*-[L,piperidine,$PtCl_2$] for the various ligands L were: $AsPr^n_3$, 18·6; PPr^n_3, 17·7; $P(OMe)_3$, 16·4; Et_2Te, 17·8; Et_2Se, 17·5; Et_2S, 17·7; C_5H_4, 13·8; 4-*n*-pentylpyridine, 17·8; piperidine, 22·6 cm.$^{-1}$.

The authors are very grateful to Professor M. J. S. Dewar for useful discussion and to Mr. P. F. Todd for experimental assistance.

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THE FRYTHE, WELWYN, HERTS. [*Received, June 13th*, 1955.]

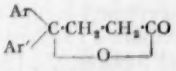
β-Aroylpropionic Acids. Part VI.* Absorption Spectra as a Tool for confirming the Structure of Some Tetra-arylbutadienes and Tetra-aryltetrahydrofurans.

By F. G. BADDAR and Z. SAWIRES.

[Reprint Order No. 6567.]

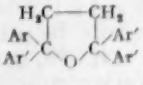
The structures of some 1 : 1 : 4 : 4-tetra-arylbuta-1 : 3-dienes and 2 : 2 : 5 : 5-tetra-aryltetrahydrofurans are confirmed by comparing absorption spectra of the former with those of 1 : 1 : 4 : 4-tetra-*p*-methoxyphenylbuta-1 : 3-diene and the corresponding 3 : 3-diarylprop-2-ene-1-carboxylic acids, and those of the latter with those of the corresponding γγ-diarylbutyrolactones and tolyl ethers.

THIS investigation was designed to confirm the structure of some tetra-arylbutadienes (II) and tetra-aryltetrahydrofurans (III), which were obtained from the action of arylmagnesium halides on succinic anhydride and β-aroylpropionic acids (cf. Baddar, El-Assal, and Habashi, *J.*, 1955, 456). Elucidation of the structure of these compounds by chemical means is practically impossible owing to the low yields and the non-reactivity. The investigation was extended to cover the relation between the tetra-arylbutadienes (II) and the corresponding 3 : 3-diarylprop-2-ene-1-carboxylic acids (IV), and between the tetra-aryltetrahydrofurans (III) and the corresponding lactones (I).

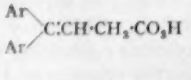


(I*a*) Ar = Ar′ = Ph
(I*b*) Ar = Ar′ = C_6H_4·OMe-*o*
(I*c*) Ar = Ar′ = C_6H_4·OMe-*p*
(I*d*) Ar = C_6H_4·OMe-*o*, Ar′ = C_6H_4·OEt-*o*

(II*a*) R = R′ = R″ = H
(II*b*) R = OMe, R′ = R″ = H
(II*c*) R = H, R′ = OMe, R″ = OEt
(II*d*) R = H, R′ = OEt, R″ = OMe



(III*a*) Ar = Ar′ = Ph
(III*b*) Ar = Ar′ = C_6H_4·OMe-*o*
(III*c*) Ar = Ar′ = C_6H_4·OEt-*o*
(III*d*) Ar = Ph, Ar′ = C_6H_4·OMe-*o*



(IV*a*) Ar = Ph
(IV*b*) Ar = C_6H_4·OMe-*o*
(IV*c*) Ar = C_6H_4·OMe-*p*

Absorption spectra were measured with a Beckman DU Quartz Spectrophotometer. The compounds were dissolved in glacial acetic acid ("AnalaR") (25 ml.) and then diluted with 95% ethyl alcohol to 100 ml., except that the acids were dissolved in 95% ethyl alcohol. The results are summarised in the Table.

* Part V, *J.*, 1955, 2199.

Compound	$\lambda_{max.}$ (mμ) †	ε	$\lambda_{min.}$ (mμ)	ε
II*b*	363	36,900	302	12,050
	~346	30,000		
	266	28,540		
II*c*	335	26,410	269	12,140
	~301	18,000		
	~290	16,600		
II*d*	334	24,710	270	11,360
	~295	15,800		
IV*a*	249	14,750	239	13,470
	~236	13,730		
IV*b*	282	6060	270	4810
	~235	13,740		
IV*c*	~291	4350	225	12,300
	~260	19,460		
	~247·5	22,050		
	246	22,260		
	~241	19,800		

Compound	$\lambda_{max.}$ (mμ) †	ε	$\lambda_{min.}$ (mμ)	ε
III*a*	259	960	—	—
	~256	850		
III*b* *	277	9200	—	—
	~262	6250		
III*c*	279	8470	277	8290
	274	8490		
III*d*	279	9280	277	9190
	273	9620		
I*a*	~263	360	—	—
	258·5	450		
	~254	370		
I*b*	278	4650	276	4550
	273	4740		
I*c*	282	2415	280	2370
	275	3030	256	1270
I*d*	278	4770	277	4700
	273	4870		

* In " AnalaR " CCl_4.

† ~ Approximate wavelength for inflexion.

Analysis of Spectra and Discussion.—(a) *Dienes and acids.* The absorption spectrum of 1 : 1 : 4 : 4-tetra-*p*-methoxyphenylbuta-1 : 3-diene (II*b*; Fig. 1) agrees well in general features with that of the related tetraphenylbutadiene (II*a*) (cf. Alberman, Haszeldine, and Kipping, *J.*, 1952, 3284), with a slight shift (20 mμ) towards the red probably due to an increase in the effective conjugation in the former compound. The increase in the intensity of the short-wavelength band may be connected with the two, nearly independently absorbing, out-of-plane, *p*-methoxyphenyl groups, which absorb at much higher wavelengths than the non-substituted phenyl groups (cf. Burawoy and Chamberlain, *J.*, 1952, 2310).

The curves for 4-*o*-ethoxyphenyl-1 : 1 : 4-tri-*o*-methoxyphenyl- (II*c*; Fig. 1) and 1 : 1 : 4-tri-*o*-ethoxyphenyl-4-*o*-methoxyphenyl-buta-1 : 3-diene (II*d*; Fig. 1) are very similar, so their structures must be chromophorically identical. They are very close to the displaced 1 : 4-diphenylbuta-1 : 3-diene absorption. In comparison with the known 1 : 1 : 4 : 4-tetra-*p*-methoxyphenylbuta-1 : 3-diene (II*b*) (cf. Tadros and Aziz, *J.*, 1951, 2555), there is a shift in the absorption bands towards the violet. This may be due to the replacement of the *o*-hydrogen atom by the bulky methoxyl or ethoxyl group, which forces rings B and C (see II) out of the plane of the rest of the butadiene system, and causes a slight twist in rings A and D. Such a steric inhibition of resonance was noticed even for 1 : 1 : 4 : 4-tetraphenylbuta-1 : 3-diene (cf. Alberman *et al.*, *loc. cit.*).

The two tetra-arylbutadienes (II*c* and *d*) differ also between themselves : the latter, with the more bulky ethoxyl groups, has a slightly lower $\lambda_{max.}$ and $\varepsilon_{max.}$ than the former. The inflexion in the curves of these two compounds at *ca.* 295 mμ may be attributed to the independently non-interacting absorption of the two o-alkoxyphenyl groups B and C. This difference between *para-* and *ortho*-substituted tetraphenylbuta-1 : 3-dienes is similar to that between *p*- and *o*-methoxycinnamic acids (Morton and Sawires, *J.*, 1940, 1063), and was termed the *para*-effect by Morton and Stubbs (*J.*, 1940, 1347).

Further support for the structure of these butadienes is the existence of a similar relation between the above cinnamic acids and the corresponding 3 : 3-diarylprop-2-ene-1-carboxylic acids (IV) (Table). The absorption of 3 : 3-diphenylprop-2-ene-1-carboxylic acid (IV*a*) is shifted to a shorter wavelength and is less intense than that of cinnamic acid ($\lambda_{max.}$ 269 mμ; ε 18,200). This may similarly be attributed to steric inhibition of resonance known in systems containing the $-CH{:}CPh_2$ group (Jones, *J. Amer. Chem. Soc.*, 1943, **65**, 1820). When the propene acid (IV*a*) is compared with the *o*-methoxy-substituted acid (IV*b*), it reflects the same relation between cinnamic acid and *o*-methoxycinnamic acid. Thus the band at 249 mμ for the propene acid (IV*a*) is shifted to longer wavelength (282 mμ) with marked decrease in intensity, while the inflexion at 236 mμ persists. The *p*-methoxy-substituted propene acid (IV*c*) bears similar relations to the parent acid (IV*a*) and the *o*-methoxy-acid (IV*b*) as those existing between the corresponding cinnamic acids, with

the high-intensity characteristic of *para*-substitution. Further confirmation for the structure of these three butadienes arises in that their solutions exhibited sky-blue fluorescence under ultraviolet irradiation (mercury-arc quartz lamp), while the tetrahydrofurans did not fluoresce (cf. Alberman *et al.*, *loc. cit.*).

(b) *Lactones and tetrahydrofurans.* γγ-Diphenylbutyrolactone (I*a*) has an absorption (Table) very near to that of diphenylmethane ($\lambda_{max.}$ *ca.* 262 mμ, ε 490) (Orndorff, Gibbs, McNulty, and Shapiro, *J. Amer. Chem. Soc.*, 1927, **49**, 1541) or nearly twice that of toluene ($\lambda_{max.}$ 262·5 mμ, ε 270). This is an agreement with expectation in that the replacement of the CH_2 group by the five-membered lactone ring will not cause major deviation from the spectrum of diphenylmethane. The substituted lactones (I*b*, *c*, and *d*) should be chromophorically equivalent to the similarly substituted diphenylmethanes or very near to the corresponding tolyl ethers (Burawoy and Chamberlain, *loc. cit.*). Although the general

FIG. 1.

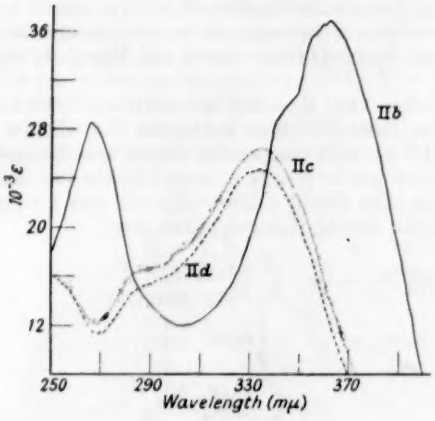
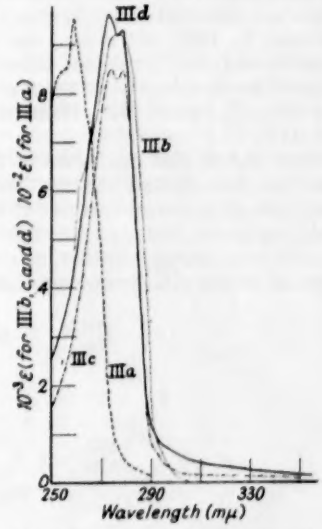


FIG. 2.



features are the same, the quantitative relations hold only roughly. This is natural, since it cannot be maintained that one carbon atom effects complete insulation of the two methoxyphenyl chromophores, resulting in $\varepsilon_{max.}$ which is higher than twice that of the corresponding cresol [*e.g.*, $\varepsilon_{max.}$ for the lactone (I*b*) = 4650, and for *o*-cresol = 1725].

Since the lactones (I) possess structures which were verified chemically (Baddar, El-Assal, and Habashi, *loc. cit.*), it was planned to support the structure of the tetra-aryltetrahydrofurans (III*b*, *c*, and *d*) by comparing their absorptions with those of tetrahydro-2 : 2 : 5 : 5-tetraphenylfuran (III*a*) (Baddar *et al.*, *loc. cit.*; Komppa and Rohrmann, *Annalen*, 1934, **509**, 259; Valeur, *Compt. rend.*, 1903, **136**, 695), and of the nearest corresponding lactones (I). The results showed that the tetrahydrofuran (III*a*) has nearly twice $\varepsilon_{max.}$ for the lactone (I*a*) (Table) or nearly 4 times that for toluene. Similarly, the tetrahydrofurans (III*b*, *c*, and *d*) had the same relation to the nearest corresponding lactones (I*b*, *c*, and *b*, respectively) (Table) and to the tolyl ethers. This similarity, as well as the non-fluorescence of these compounds in ultraviolet light, afford good support for the furan structures.

The authors express their gratitude to the U.S. Naval Medical Research Unit No. 3, Cairo, Egypt, for facilities to use their Beckman Spectrophotometer in this investigation.

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The Preparation and Reactions of Dialkyl-(o-dialkylphosphinophenyl)-arsines.

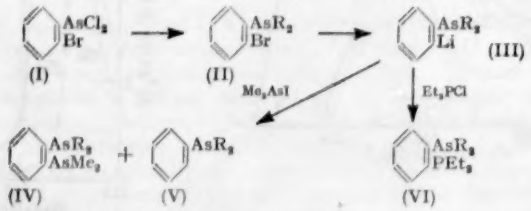
By Emrys R. H. Jones and Frederick G. Mann.

[Reprint Order No. 6607.]

Two members of the above novel type of ditertiary phosphine-arsine have been prepared. They act as strong chelating agents with metals and are thus of considerable stereochemical value. They also undergo diquaternisation with various alkylene dibromides to form cyclic phosphonium-arsonium dibromides, the thermal decomposition of which has been studied. These water-soluble dibromides are of no significant value as schistosomicides.

o-Phenylenebis(dimethylarsine) (IV; R = Me) is a compound of wide application, for it acts as a powerful chelating group with metallic salts (Chatt and Mann, *J.*, 1939, 610: cf. Nyholm, *J.*, 1950, 851 *et seq.*) and also undergoes ready diquaternisation with ethylene, trimethylene, and *o*-xylylene dibromides to give cyclic diarsine dimethobromides, from which in turn various novel types of cyclic arsenic derivatives have been obtained (Glauert and Mann, *J.*, 1950, 682; Mann and Baker, *J.*, 1952, 4142; Jones and Mann, *J.*, 1955, 405, 411).

The diphosphine analogues of this diarsine (IV; R = Me) are unknown. We have therefore investigated the synthesis of the monophosphine analogues, *i.e.*, dialkyl-(*o*-dialkylphosphinophenyl)arsines of type (VI), for such compounds would also be strong chelating agents, but their stereochemical value will be greatly increased by the two unlike co-ordinating atoms: further, quaternisation with alkylene dibromides will now give new types of heterocyclic compounds having arsenic and phosphorus in one ring.

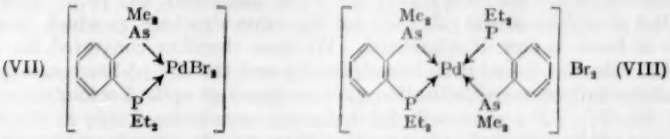


We find that *o*-bromophenyldichloroarsine (I) when treated with methylmagnesium bromide gives *o*-bromophenyldimethylarsine (II; R = Me), which with *n*-butyl-lithium readily affords the *o*-lithio-derivative (III; R = Me). To test the activity of this compound, it was treated with dimethyliodoarsine, whereby *o*-phenylenebis(dimethylarsine) (IV; R = Me) and phenyldimethylarsine (V; R = Me) were obtained in 50% and 5% yield respectively. Treatment of the lithio-derivative with chlorodiethylphosphine gave *o*-diethylphosphinophenyldimethylarsine (VI; R = Me), and repetition of the synthesis, with *o*-bromophenyldiethylarsine (II; R = Et), afforded *o*-diethylphosphinophenyldiethylarsine (VI; R = Et).

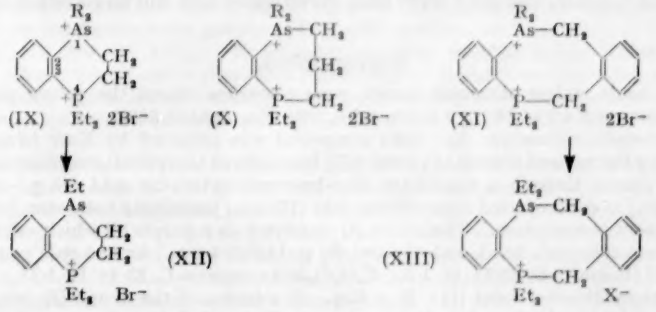
The strongly chelating properties of these phosphine-arsines are shown by the ready reaction of the former (VI; R = Me) with potassium palladobromide to give, under appropriate conditions, the covalent dibromo-*o*-diethylphosphinophenyldimethylarsine-palladium (VII) and the salt, bis-(*o*-diethylphosphinophenyldimethylarsine)palladium dibromide (VIII), both highly crystalline yellow compounds. The cation in the salt (VIII), being planar, could clearly exist is *cis*- and *trans*-forms: no indication of a mixture could be detected, and it is highly probable that the salt has the *trans*-configuration (VIII). An *X*-ray crystal structure investigation of this compound is now being carried out by Dr. S. C. Nyburg at the University College of North Staffordshire.

It is noteworthy that, although the phosphine-arsine (VI; R = Me) reacted vigorously when dissolved in an excess of cold methyl iodide, only a monomethiodide could be isolated:

the homologue (VI; R = Et) behaved similarly, with the formation, however, of a mono- and a di-methiodide in the ratio 5 : 1. There is little doubt that these monomethiodides are quaternary phosphonium salts, for Davies and Lewis (*J.*, 1934, 1599) have shown that the speed of quaternisation of tertiary phosphines is greater than that of the corresponding arsines. The stability of the monomethiodides is undoubtedly due to the fact that the positive charge on the quaternised phosphorus atom partially deactivates the tertiary arsine group: the same effect is shown by the diarsine (IV; R = Me), a solution of which in methyl iodide, when boiled under reflux for several hours, forms only a monomethiodide but when heated with methanol at 100° gives a dimethiodide (Mann and Baker, *loc. cit.*).



When, however, the phosphine-arsine (VI; R = Me) was heated with ethylene dibromide, trimethylene dibromide, or *o*-xylylene dibromide, ready cyclisation by diquaternisation occurred, with the formation of the diquaternary dibromides (IX, X, and XI; R = Me). The use of the phosphine-arsine (VI; R = Et) gave the corresponding 1 : 1 : 4 : 4-tetraethyl salts. The structure of all these salts was confirmed by the fact that treatment in cold ethanolic solution with sodium picrate gave the corresponding dipicrates, and hence diquaternisation involving cyclisation must have occurred.



The thermal decomposition of the salts (IX and XI; R = Et) has been investigated. It is known that the 1 : 1 : 4 : 4-tetramethyldiarsonium analogue of (IX) when heated loses methyl bromide (2 mols.) with the formation of 1 : 4-dimethylethylene-*o*-phenylenediarsine, whereas the same analogue of (XI) undergoes a complex reaction, with the formation of *o*-phenylenebis-(2-*iso*arsindoline). It was expected that the phosphine-arsine salts (IX and XI; R = Et) would similarly lose ethyl bromide readily from the quaternary arsonium group, but that the decomposition of the quaternary phosphonium group, involving the loss of ethylene and hydrogen bromide, would require a higher temperature, and might thus involve general decomposition. This has proved to be the case. The dibromide (IX; R = Et) when heated at 270°/15 mm. for 5 minutes lost ethyl bromide and gave the crystalline 1 : 4 : 4-triethylethylene-*o*-phenylene-1-arsine-4-phosphonium bromide (XII): when this initial effervescence had ceased, the temperature was increased to 350°/2 mm., causing a slow secondary effervescence, accompanied by general decomposition, liberation of elementary arsenic, and the production of a very small intractable distillate which had no reactions of a tertiary phoshine or arsine. The identity of the bromide (XII) was confirmed by the reconversion of the salt, when heated with ethanolic ethyl bromide, into the dibromide (IX; R = Et).

Similarly the dibromide (XI; R = Et) when heated at 270°/15 mm. lost ethyl bromide, forming 1 : 4 : 4-triethyl-*o*-phenylene-*o*-xylylene-1-arsine-4-phosphonium bromide (XIII;

X = Br), identified as the crystalline iodide (XIII; X = I), but further heating to 330°/2 mm. caused charring and deposition of arsenic, and no distillate was obtained. Further attempts to prepare the cyclic ditertiary phosphine-arsines were therefore abandoned.

The stereochemical features of the *o*-xylylene salt (XI) are of particular interest. *X*-Ray crystal evidence showed that the corresponding 1 : 1 : 4 : 4-tetramethyl-diarsonium dibromide has the simple structure (as XI), *i.e.*, that no question of a " dimer " with a central 16-membered ring arises: this structure (as XI) can theoretically exist in *cis*- and *trans*-forms, which should not be interconvertible, and the above evidence also indicates strongly, but not conclusively, that this salt has the *trans*-structure (for diagrams and detailed discussion of the stereochemistry see Jones and Mann, *loc. cit.*). There is little doubt that the phosphine-arsine salt (XI) has the same structure, in which, however, the cation, if *cis* or *trans*, is now dissymmetric. We have therefore converted the dibromide (XI; R = Et) into the di-(+)-camphorsulphonate and the di-(+)-bromocamphorsulphonate, but neither salt on recrystallisation gave evidence of optical resolution. The (+)-tartrate and the di-(−)-*N*-1-phenylethylphthalamate were isolated only as viscous syrups.

Very little is known about the therapeutic action of cyclic arsenic compounds and even less about that of similar phosphorus compounds. Since furthermore, the water-soluble salts (IX, X, and XI; R = Et) represent new cyclic systems, their action as possible schistosomicides has kindly been investigated by Mr. O. D. Standen at the Wellcome Laboratories of Tropical Medicine: they prove to be of no significant value for this purpose. The compound (XII) has apparently some schistosomicidal action, the assessment of which, however, is made difficult by the relatively high toxicity.

The co-ordinated derivatives of the phosphine-arsines (VI) with various metals, particularly copper, silver, and gold, have been investigated and will be recorded later.

Experimental

All compounds, unless otherwise stated, were colourless except the yellow picrates. All rotations were measured at 16° in a 4 dm. tube, with Na_D light (λ 5893).

o-Bromophenyldichloroarsine (I).—This compound was prepared by Kalb (*Annalen*, 1921, **423**, 69) and by Burton and Gibson (*J.*, 1926, 457) but without analytical identification. Sulphur dioxide was passed through a suspension of *o*-bromophenylarsonic acid (75 g.) (Burton and Gibson, *loc. cit.*) in concentrated hydrochloric acid (750 c.c.) containing potassium iodide (0·5 g.) for 3 hr. at room temperature. The *arsine* (I) separated as a purple oil which solidified (76 g., 95%) and when collected, dried, and distilled (b. p. 110°/0·5 mm.) formed pale yellow crystals, m. p. 62—64° (Found: C, 23·7; H, 1·5. $C_6H_4Cl_2BrAs$ requires C, 23·8; H, 1·3%).

o-Bromophenyldimethylarsine (II; R = Me).—A solution of the arsine (I) (40 g.) in ether (200 c.c.) was slowly added under nitrogen to a well-stirred Grignard reagent prepared from methyl iodide (18 c.c., 2·2 mols.) and magnesium (7·0 g., 2·2 atoms) in ether (200 c.c.). After the vigorous reaction had subsided, the mixture was stirred for 15 min. and then hydrolysed by adding ammonium chloride (50 g.) in aqueous solution. Distillation of the dried ethereal layer gave the *arsine* (II; R = Me) (26 g., 76%), b.p. 85—86°/0·8 mm. (Found: C, 37·2; H, 4·2. $C_8H_{10}BrAs$ requires C, 36·8; H, 3·8%). It has a characteristic radish-like odour, and is fairly readily oxidised by air. *o-Bromophenyltrimethylarsonium iodide* readily crystallised from a mixture of the arsine and methyl iodide at room temperature, and when recrystallised from methanol decomposed at *ca.* 240° without melting (Found: C, 27·1; H, 3·3. $C_9H_{13}BrIAs$ requires C, 26·8; H, 3·2%).

o-Bromophenyldiethylarsine (II; R = Et), similarly prepared by using the arsine (I) (105 g.), ethyl bromide (78 c.c.; 3 mols.), and magnesium (25·0 g., 3 atomic equivs.), had b. p. 109—110°/1 mm. (Found: C, 41·85; H, 5·0. $C_{10}H_{14}BrAs$ requires C, 41·5; H, 4·8%): 84 g., 84%. It gave *o-bromophenyldiethylmethylarsonium iodide*, m. p. 114—115° after crystallisation from ethanol (Found: C, 30·4; H, 4·1. $C_{11}H_{17}BrIAs$ requires C, 30·6; H, 3·9%).

Lithiation of o-Bromophenyldimethylarsine (II; R = Me).—This arsine did not react with magnesium turnings or activated magnesium powder; it reacted only slowly with metallic lithium in ether, but readily with *n*-butyl-lithium in light petroleum. Whilst the preparation of the compounds described below was in progress, Gilman and Avakian (*J. Amer. Chem. Soc.*, 1954, **76**, 4031) described the lithiation of various dialkyl-*p*-bromophenylarsines and the reaction of the products with quinoline to form the corresponding 2-(*p*-dialkylarsinophenyl)quinolines.

A solution of the arsine (II; R = Me) (2·75 g.) in light petroleum (b. p. 40—60°) (10 c.c.) was added under nitrogen to a 1·31N-solution (8·8 c.c.) of *n*-butyl-lithium (1·1 mols.), also in light petroleum. The mixture was boiled under reflux for 4 hr., cooled, treated with dimethyliodoarsine (2·4 g., 1 mol.), and boiled for 1 hr. more. After cooling and hydrolysis with water, the dried organic layer on distillation gave the fractions: (*a*) phenyldimethylarsine (V), b. p. 95—110°/14 mm. (0·15 g.); (*b*) *o*-phenylenebis(dimethylarsine) (IV; R = Me), b. p. 150—156°/15 mm. (1·5 g., 50%).

Fraction (*a*) gave phenyltrimethylarsonium iodide, m. p. 244—245° (effervescence) after crystallisation from ethanol (Found: C, 33·2; H, 4·6. Calc. for $C_9H_{14}IAs$: C, 33·3; H, 4·3%). Michaelis and Link (*Annalen*, 1881, **207**, 205) give m. p. 244°.

Fraction (*b*) also gave a monomethiodide (at room temperature), m. p. 220—222°, alone and mixed with an authentic sample. Chatt and Mann (*loc. cit.*) give b. p. 156°/20 mm. for the diarsine.

This experiment showed the success of the method, which was applied virtually unchanged to the preparation of the following compound (VI; R = Me) but was modified for that of the homologue (VI; R = Et) (see below).

o-*Diethylphosphinophenyldimethylarsine* (VI; R = Me).—A solution of the arsine (II; R = Me) (14·4 g.) in light petroleum (50 c.c.) was added to one of 1·31N-*n*-butyl-lithium (50 c.c., 1·2 mols. of solute) in light petroleum, which was then boiled under reflux for 5 hr., cooled, and treated with chlorodiethylphosphine (6·9 g., 1 mol.). Working up as in the above experiment gave the fractions: (*a*) b. p. 84—86°/19 mm. (*ca.* 1 g.), phenyldimethylarsine, identified as its methiodide, m. p. and mixed m. p. 244°; (*b*) b. p. 95—130°/19 mm. (2·3 g.) (no component was identified); (*c*) b. p. 152—170°/22 mm. (7·3 g., 49%), crude phosphine-arsine (VI; R = Me). It was noteworthy that this compound and the diethyl analogue (VI; R = Et) on refractionation gave constant b. p.s but consistently poor analyses. Thus fraction (*c*) when carefully refractionated had b. p. 100—102°/0·6 mm. (Found: C, 57·4; H, 8·5. Calc. for $C_{12}H_{20}PAs$: C, 53·3; H, 7·4%); a second fractionation gave b. p. 105—107°/0·6 mm., and a third, b. p. 105—106°/0·6 mm. (Found: C, 56·0; H, 7·4%). No impurity could be detected during the preparation of derivatives. A mixture of the final product and an equal volume of methyl iodide gave a vigorous reaction with deposition of crystals, which on recrystallisation from ethanol gave the P-*methiodide monohydrate*, m. p. 162°—163° (Found: 36·4; H, 5·6. $C_{15}H_{23}IAsP,H_2O$ requires C, 36·3; H, 5·8%).

Palladium Derivatives.—When solutions of the phosphine-arsine (0·50 g.) in hot ethanol and of potassium palladobromide (1·00 g., 1·06 mol.) in a minimum of water were mixed, an almost insoluble reddish-brown precipitate, probably the salt $[(C_{12}H_{20}PAs)_2Pd][PdBr_4]$, was formed (cf. Chatt and Mann, *loc. cit.*). A mixture of this product, 48% hydrobromic acid (10 c.c.), and ethanol (10 c.c.), when boiled under reflux for 3 hr., gave a deep red solution, which on cooling deposited *dibromo-o-diethylphosphinophenyldimethylarsinepalladium* (VII), yellow crystals, m. p. 308° (decomp.) after crystallisation from ethanol (Found: C, 27·3; H, 4·0. $C_{12}H_{20}Br_2PAsPd$ requires C, 26·8; H, 3·75%).

Repetition of the above procedure, using the phosphine-arsine (0·60 g.) and the palladobromide (0·57 g., 0·50 mol.), gave a yellow solution which was evaporated to dryness in a desiccator. The residue, when recrystallised from ethanol, gave *bis-(o-diethylphosphinophenyldimethylarsine)palladium dibromide monohydrate* (VIII), yellow crystals, m. p. 266—267° (Found: C, 35·1; H, 5·2. $C_{24}H_{40}Br_2P_2As_2Pd,H_2O$ requires C, 34·9; H, 5·1%). This salt gave the deep yellow *dipicrate*, m. p. 236° (decomp.) from aqueous acetone (Found: C, 39·5; H, 4·2; N, 7·9. $C_{36}H_{44}O_{14}N_6P_2As_2Pd$ requires C, 39·2; H, 4·0; N, 7·6%).

Diethyl-o-diethylphosphinophenylarsine (VI; R = Et).—The preparation of this compound was investigated more fully than that of its analogue (VI; R = Me). It was found that the use of ether to dissolve the arsine (II; R = Et) accelerated the lithiation (the period of boiling being reduced to 1 hr.), prevented the formation of the arsine (V; R = Et) as a by-product, and increased the yield of the phosphine-arsine (VI; R = Et). The 1·80N-light petroleum solution of *n*-butyl-lithium (220 c.c., 1·05 mols. of solute) was therefore treated in turn with the arsine (II; R = Et) (109 g.) in ether (200 c.c.) and with chlorodiethylphosphine (47 g., 1·0 mol.). After working up as before, distillation gave the fractions: (*a*) b. p. 90—125°/2·5 mm. (14·1 g.), of unidentified composition; (*b*) b. p. 147—152°/3 mm. (70·5 g.). This crude phosphine-arsine (63% yield) on refractionation gave a sample, b. p. 131—132°/0·8 mm. (Found: C, 57·8; H, 8·9. Calc. for $C_{14}H_{24}PAs$: C, 56·3; H, 8·1%), and when again fractionated, a sample, b. p. 136°/1·0 mm. (Found: C, 57·6; H, 7·9%).

The addition of methyl iodide to an equal volume of the cold phosphine-arsine caused the

mixture to boil and to precipitate the *dimethiodide*, m. p. 165° (effervescence) after crystallisation from ethanol (Found: C, 33·0; H, 4·8. $C_{16}H_{36}I_2PAs$ requires C, 33·0; H, 5·2%). Addition of ether to the filtrate from the reaction mixture precipitated the P-*monomethiodide*, m. p. 148—149° after crystallisation from water (Found: C, 41·0; H, 6·2. $C_{15}H_{27}IPAs$ requires C, 40·85; H, 6·2%). The ratio of the weights of these salts was *ca.* 1 : 5.

Cyclic Diquaternisation with Dibromides.—All the following reactions were carried out in a nitrogen atmosphere. (A) *Derivatives of the phosphine-arsine* (VI; R = Me). (1) A mixture of the compound (VI; R = Me) (0·5 g.) and ethylene dibromide (0·16 c.c., 1 mol.) was heated at 90° for 15 min. and at 120° for 2 hr. The mixture solidified considerably during the earlier period, and violent " bumping " was thus avoided. The final hard product, when recrystallised from methanol, afforded 4 : 4-*diethyl*-1 : 1-*dimethylethylene*-o-*phenylene*-1-*arsonium*-4-*phosphonium dibromide dihydrate* (IX; R = Me), m. p. 235—245° (effervescence) (Found: C, 34·5; H, 6·2. $C_{14}H_{24}Br_2PAs,2H_2O$ requires C, 34·1; H, 5·8%). The *dipicrate* formed crystals, m. p. 196—197° from methanol (Found: C, 41·3; H, 3·7; N, 11·1. $C_{26}H_{28}O_{14}N_6PAs$ requires C, 41·2; H, 3·7; N, 11·1%).

(2) Repetition of this experiment, using however trimethylene dibromide (0·19 c.c., 1 mol.), gave a product which, recrystallised from methanol–ethanol, afforded 4 : 4-*diethyl*-1 : 1-*dimethyltrimethylene*-o-*phenylene*-1-*arsonium*-4-*phosphonium dibromide monohydrate* (X; R = Me), m. p. 245—257° (effervescence) (Found: C, 36·7; H, 5·6. $C_{15}H_{26}Br_2PAs,H_2O$ requires C, 36·7; H, 5·7%). It gave a *dipicrate*, m. p. 201—202° after crystallisation from acetone–ethanol (Found: C, 42·3; H, 3·9; N, 10·8. $C_{27}H_{30}O_{14}N_6PAs$ requires C, 42·2; H, 3·9; N, 10·9%).

(3) A solution of the compound (VI; R = Me) (0·5 g.) in warm methanol (2 c.c.) was added to one of *o*-xylylene dibromide (0·49 g., 1 mol.) in methanol (5 c.c.) which was set aside overnight. The crystalline hygroscopic deposit, when recrystallised from methanol, gave 4 : 4-*diethyl*-1 : 1-*dimethyl*-o-*phenylene*-o-*xylylene*-1-*arsonium*-4-*phosphonium dibromide hemihydrate* (XI; R = Me), m. p. 208—209° (effervescence) (Found: C, 44·3; H, 5·8. $C_{20}H_{28}Br_2PAs,\frac{1}{2}H_2O$ requires C, 44·25; H, 5·4%). The *dipicrate* formed crystals, m. p. 188° from acetone–ethanol (Found: C, 46·5; H, 3·9; N, 10·2. $C_{32}H_{32}O_{14}N_6PAs$ requires C, 46·25; H, 3·9; N, 10·1%).

(B) *Derivatives of the phosphine-arsine* (VI; R = Et). These were prepared as their above analogues. (1) 1 : 1 : 4 : 4-*Tetraethylethylene*-o-*phenylene*-1-*arsonium*-4-*phosphonium dibromide* (IX; R = Et) had m. p. 223° (effervescence) when crystallised from ethanol (70% yield) (Found: C, 39·3; H, 6·0. $C_{16}H_{28}Br_2PAs$ requires C, 39·5; H, 5·8%); it gave a *dipicrate*, m. p. 215° (decomp.) when crystallised from acetone–ethanol (Found: C, 42·9; H, 4·4; N, 10·95. $C_{28}H_{32}O_{14}N_6PAs$ requires C, 42·9; H, 4·1; N, 10·7%).

(2) The use of trimethylene dibromide afforded 1 : 1 : 4 : 4-*tetraethyltrimethylene*-o-*phenylene*-1-*arsonium*-4-*phosphonium dibromide* (X; R = Et), m. p. 240° (effervescence) after crystallisation from methanol (50% yield) (Found: C, 41·1; H, 6·4. $C_{17}H_{30}Br_2PAs$ requires C, 40·8; H, 6·05%); it gave a *dipicrate*, m. p. 221° (decomp.) after crystallisation from acetone (Found: C, 43·7; H, 4·3; N, 10·5. $C_{29}H_{34}O_{14}N_6PAs$ requires C, 43·7; H, 4·3; N, 10·55%).

(3) *o*-Xylylene dibromide gave 1 : 1 : 4 : 4-*tetraethyl*-o-*phenylene*-o-*xylylene*-1-*arsonium*-4-*phosphonium dibromide* (XI; R = Et), m. p. 234° (effervescence) after crystallisation from aqueous methanol (48% yield) (Found: C, 47·2; H, 5·9. $C_{22}H_{32}Br_2PAs$ requires C, 47·0; H, 5·7%); it gave a *dipicrate*, precipitated from aqueous solution and recrystallised from aqueous dimethylformamide, m. p. 208° (decomp.) (Found: C, 47·5; H, 4·5; N, 9·95. $C_{34}H_{36}O_{14}N_6PAs$ requires C, 47·5; H, 4·2; N, 9·8%).

Thermal Decomposition of the Dibromides.—(1) *The dibromide* (IX; R = Et). The finely powdered salt, when heated at 270°/15 mm. for 15 min., effervesced, losing ethyl bromide. The residue, when recrystallised from ethanol–acetone, afforded 1 : 4 : 4-*triethylethylene*-o-*phenylene*-1-*arsine*-4-*phosphonium bromide* (XII), m. p. 167—169° (Found: C, 44·9; H, 6·2. $C_{14}H_{23}BrPAs$ requires C, 44·6; H, 6·15%). When, however, the above residue, after the initial effervescence had subsided, was heated at 350°/2 mm., a secondary effervescence occurred, with much general decomposition and deposition of arsenic. The very small distillate consisted of a thick gum and a mobile liquid, but neither would give an ethobromide, a crystalline palladium dibromide derivative, or (after oxidation) a hydroxynitrate, and it is improbable therefore that either was a tertiary arsine or phosphine.

A mixture of the bromide (XII) (0·5 g.), ethyl bromide (1 c.c.), and ethanol (1 c.c.), when heated in a sealed tube at 100° for 6 hr., regenerated the dibromide (IX; R = Et), m. p. and mixed m. p. 223° (effervescence) after recrystallisation.

(2) *The dibromide* (XI; R = Et). This salt when heated at 270°/15 mm. lost ethyl bromide with effervescence, giving a residue of the bromide (XIII; X = Br), which formed a glass which

could not be recrystallised, and did not give a crystalline picrate. Its aqueous solution, when treated with aqueous sodium iodide, deposited 1 : 4 : 4-*triethyl*-o-*phenylene*-o-*xylylene*-1-*arsino*-4-*phosphonium iodide* (XIII; X = I), m. p. 222—224° after crystallisation from ethanol (Found: C, 48·3; H, 5·6. $C_{30}H_{37}IPAs$ requires C, 48·0; H, 5·4%). When the dibromide (XI; R = Et) was heated to 330°/2 mm., extensive charring and deposition of arsenic occurred, and no distillate was obtained.

Attempted Resolution of the Dibromide (XI; R = Et).—(*a*) Aqueous solutions of the dibromide and of silver (+)-camphorsulphonate were mixed, boiled for a few min., filtered, and evaporated to dryness. The residual *di*-(+)-*camphorsulphonate monohydrate* had m. p. 252° (decomp.) after one and after eight recrystallisations from ethanol (Found: C, 56·8; H, 7·2. $C_{42}H_{62}O_8S_2PAs,H_2O$ requires C, 57·1; H, 7·3%), the weight of salt falling from 3·18 g. to 0·35 g. meanwhile. A 1·152% aqueous solution of the final product had α +0·57°, $[M]$ +105°. The two anions have $[M]$ +100° (Graham, *J.*, 1912, **101**, 746) and resolution was therefore not occurring.

(*b*) The *di*-(+)-*bromocamphorsulphonate*, similarly prepared, had m. p. 253° (decomp.) after one and after ten recrystallisations from methanol (Found: C, 49·2; H, 5·7. $C_{42}H_{60}O_8Br_2S_2PAs$ requires C, 49·3; H, 5·9%), the weight falling from 4·17 g. to 1·13 g. A 0·9057% aqueous solution then had α +1·96°, $[M]$ +553°: the two anions alone have $[M]$ +556° (Pope and Read, *J.*, 1910, **97**, 2201).

The (+)-tartrate and the di-(−)-*N*-1-phenylethylphthalamate were similarly prepared by the interaction of the dibromide (XI; R = Et) and the silver salt in aqueous solution and suspension respectively. Each formed a viscous syrup which could not be crystallised.

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UNIVERSITY CHEMICAL LABORATORY, CAMBRIDGE. [*Received, July 12th*, 1955.]

Synthesis of the Mononitrophenanthrenes.

By P. M. G. BAVIN and M. J. S. DEWAR.

[Reprint Order No. 6651.]

The mononitrophenanthrenes, apart from the 1- and the 9-isomer, have hitherto been obtained only by the nitration of phenanthrene. All five isomers have now been synthesised from the corresponding amines; in addition 2-nitrophenanthrene has been obtained by Wagner–Meerwein rearrangement of 2-nitro-9-fluorenylmethyl acetate. The properties of the 2- and the 4-isomer differ significantly from those described by previous workers.

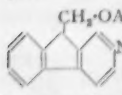
SCHMIDT and HEINLE (*Ber.*, 1911, **44**, 1488) studied the nitration of phenanthrene and claimed to have isolated from the reaction four isomeric mononitrophenanthrenes in the following proportions: 9-, 60%; 2-, 20%; 4-, 20%; 3-, 2%. They reported that, despite an intensive search, they could find no trace of the 1-isomer.

These results are very much at variance with predictions made by one of us (Dewar, *J. Amer. Chem. Soc.*, 1952, **74**, 3357) on the basis of molecular-orbital theory, which suggest that the order of reactivity of the sites in phenanthrene should be $9 > 1 > 4 > 3 > 2$. However, separation of isomeric phenanthrene derivatives is often very difficult even with the use of modern techniques, so it seemed likely that Schmidt and Heinle's results were in error. This impression is supported by the properties reported by them for their mononitrophenanthrenes; for example, the 2-isomer was stated to be impure while the "4-isomer" was reduced to an amine of m. p. 105°, whereas authentic 4-aminophenanthrene, prepared later by Langenbeck and Weissenhorn (*Ber.*, 1939, **72**, 724), has m. p. 55°.

We therefore reinvestigated the nitration of phenanthrene, and as a preliminary, prepared all five mononitrophenanthrenes by unambiguous methods. Previously only the 1- and the 9-isomer had been synthesised (Hey and Osbond, *J.*, 1949, 3172; Cook and Moffatt, *J.*, 1951, 2487), the rest having been isolated by laborious fractional crystallisation from the mixtures of isomers formed in the nitration of phenanthrene.

The nitrophenanthrenes could be prepared from the corresponding aminophenanthrenes by treating the corresponding diazonium cobaltinitrites with " cupric nitrite " and freshly precipitated cuprous oxide (cf. Hodgson and Marsden, *J.*, 1944, 22). The yields were very poor (5—6%), but reproducible. The diazonium fluoroborates gave similar yields under the same conditions and, since they proved much easier to prepare, they have been used throughout. We found, in agreement with Hodgson and Marsden, that freshly precipitated cuprous oxide is essential for the formation of the nitro-compounds. Copper bronze, added under the same conditions or used alone, prevented the formation of nitro-compounds (cf. Starkey, *Org. Synth.*, Coll. Vol. II, p. 225).

We also obtained 2-nitrophenanthrene by a very much better method, based on the synthesis of phenanthrene by Wagner–Meerwein rearrangement of 9-fluorenylmethanol.



(I)

Acetylation of 9-fluorenylmethanol with *iso*propenyl acetate gave the corresponding acetate, which could be nitrated in good yield to 2-nitro-9-fluorenylmethyl acetate (I). When this was heated with polyphosphoric acid, 2-nitrophenanthrene was formed in excellent yield. Attempts are being made to extend this method to the other nitrophenanthrenes and related compounds.

The melting points of the pure mononitrophenanthrenes are tabulated alongside those reported previously. It is curious that the m. p. reported by Schmidt and Heinle for the 4-isomer coincides with that found by us; the melting points of the amine (105°) and acetamido-derivative (190°) obtained by Schmidt and Heinle from their 4-isomer differ from those of pure 4-amino- (m. p. 55°) and 4-acetamido-phenanthrene (m. p. 203—204°). Our 1-nitrophenanthrene was identical with a specimen very kindly provided by Professor D. H. Hey.

	Melting point	
Nitrophenanthrene	This work	Previous work
1-	133°	133° [a]
2-	119—120	99 [b]
3-	172—174	171 [b]
4-	82	80—82 [b]
9-	118	118 [b]

[a] Hey and Osbond, *loc. cit.* [b] Schmidt and Heinle, *loc. cit.*; Cook and Moffatt, *loc. cit.*, report m. p. 113—114° for the 9-isomer.

Experimental

9-*Nitrophenanthrene.*—A solution of 9-aminophenanthrene (3 g.) (Bachmann and Boatner, *J. Amer. Chem. Soc.*, **1936**, **58**, 2098) in dioxan (10 ml.) was added to a stirred ice-cold solution of hydrochloric acid (10 ml.) in water (100 ml.). A solution of sodium nitrite (1·25 g.) in water (5 ml.) was added in one portion and the solution stirred at 0° for ½ hr. Hydrofluoroboric acid (15 ml. of 40%) was added, and after a further ½ hour's stirring the yellow precipitate of 9-phenanthryldiazonium fluoroborate was collected and dried in a vacuum. The dry finely powdered fluoroborate was added gradually to a stirred mixture of sodium nitrite (20 g.), cupric sulphate (20 g.), freshly prepared cuprous oxide (5 g.), and water (400 ml.). Stirring was continued for 1 hr. and the mixture left overnight. Next day the organic material was extracted with chloroform (4 × 100 ml.), and the combined extracts were washed with water, dried and evaporated. The residual black tar was chromatographed from light petroleum on alumina, the pale yellow and least strongly adsorbed band being eluted. After a further chromatographic purification and successive crystallisations from light petroleum and ethanol, 9-nitrophenanthrene was obtained in pale yellow needles (0·26 g., 7·5%), m. p. 118° (Found: C, 75·4; H, 4·2; N, 6·3. Calc. for $C_{14}H_9O_2N$: C, 75·3; H, 4·1; N, 6·3%).

1-*Nitrophenanthrene.*—1-Aminophenanthrene (Langenbeck and Weissenhorn, *loc. cit.*) was converted into 1-nitrophenanthrene in 60% yield by the method used for the 9-isomer; chromatography from light petroleum on alumina and crystallisation from ethanol gave material of m. p. 133°, undepressed by a specimen prepared by Hey and Osbond (*loc. cit.*) and supplied to us by Professor D. H. Hey.

4-*Nitrophenanthrene.*—Prepared as above from β-2-naphthoylpropionic acid, 4-nitrophenanthrene crystallised from light petroleum in pale yellow prisms, m. p. 82° (Found: C, 75·7; H, 4·2; N, 6·1%). The yields in the Langenbeck–Weissenhorn reaction (12%), and in the conversion of the amine into the nitro-compound (1·7%), were very poor.

2-*Nitrophenanthrene.*—2-Acetylphenanthrene (Mosettig and van de Kamp, *J. Amer. Chem.*

Soc., 1930, **52**, 3704) was converted into 2-nitrophenanthrene by the method used for the 9-isomer. The nitro-compound, after chromatography from light petroleum on alumina, crystallised from 50% acetic acid in bright yellow needles (yield, 6%), m. p. 119—120° (Found: C, 75·4; H, 4·0; N, 6·25%).

3-*Nitrophenanthrene*.—Prepared in 5% yield by the method used for the 2-isomer, 3-nitrophenanthrene crystallised from light petroleum in pale yellow needles, m. p. 172—174°.

9-*Fluorenylmethyl Acetate*.—Pure 9-fluorenylmethanol (12·2 g.) (Burr, *ibid.*, 1951, **73**, 823) was boiled under reflux with *iso*propenyl acetate (140 g.) containing sulphuric acid (2 drops) for 2½ hr. Sodium hydrogen carbonate (1 g.) was then added, most of the solvent distilled off, and the residue diluted with light petroleum, treated with a little fuller's earth and evaporated. The residue crystallised from light petroleum, giving 9-fluorenylmethyl acetate (11·6 g., 80%) as prisms, m. p. 87° (lit., 84—85°) (Found: C, 80·6; H, 6·0. Calc. for $C_{16}H_{14}O_2$: C, 80·4; H, 5·9%). Treatment of a portion with polyphosphoric acid for 30 min. at 160—165° gave phenanthrene in good yield.

2-*Nitro*-9-*fluorenylmethyl Acetate*.—9-Fluorenylmethyl acetate (6·5 g.) was dissolved in warm acetic anhydride (20 ml.) and the solution cooled to 30—35°. Fuming nitric acid (1·45 ml.; *d* 1·5) in acetic anhydride (2 ml.) was added with shaking. After being kept at room temperature overnight, the solution was left at 0° for 24 hr. Pale yellow crystals separated and were collected (4·0 g., 52%). Recrystallisation from glacial acetic acid gave 2-*nitro*-9-*fluorenylmethyl acetate* as pale yellow prisms, m. p. 125—126° (Found: C, 67·6; H, 4·7; N, 5·0. $C_{16}H_{13}O_4N$ requires C, 67·8; H, 4·6; N, 4·95%). Dilution of the mother-liquors gave crystals of lower m. p. The nitro-ester was soluble in concentrated sulphuric acid to an orange solution. Attempted hydrolysis with ethanol–hydrochloric acid, or with potassium ethoxide–ethylene glycol, gave impure products. Fission of the ester group with hydrazine also gave an impure product.

2-*Nitrophenanthrene*.—The nitro-ester (1 g.) was added to hot, stirred polyphosphoric acid (50 ml.), and the resulting bright yellow solution kept at 160—165° for ½ hr. A dark oil separated. After cooling, the mixture was diluted with water and the solid collected and dried (0·7 g., 89%). Crystallisation from ethanol gave bright yellow needles, m. p. 120—121°, undepressed on admixture with 2-nitrophenanthrene.

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The Rapson Triphenylene Synthesis and its Application to 1 : 2-3 : 4-*Dibenzophenanthrene.*

By P. M. G. BAVIN and M. J. S. DEWAR.

[Reprint Order No. 6652.]

The structure of the intermediate in Rapson's triphenylene synthesis (*J.*, 1941, 15) has been confirmed as octahydrotriphenylene, formed by oxidative cyclodehydration; the same intermediate is obtained when cyclisation is effected with polyphosphoric acid or anhydrous hydrogen fluoride. An extension of the synthesis to 1 : 2-3 : 4-dibenzophenanthrene is described.

RAPSON (*J.*, 1941, 15) showed that treatment of 2-*cyclo*hex-1′-enyl-1-phenyl*cyclo*hexanol (I; R = Ph) with aluminium chloride gave a hydrocarbon which was dehydrogenated smoothly to triphenylene. On the basis of this reaction, and analysis of the hydrocarbon and its picrate, the hydrocarbon was formulated as 1 : 2 : 3 : 4 : 5 : 6 : 7 : 8-octahydrotriphenylene (II).

We have found that the alcohol (I) gives the same hydrocarbon on treatment with polyphosphoric acid or anhydrous hydrogen fluoride. This is surprising, if the hydrocarbon is indeed an octahydrotriphenylene, for such a compound could be formed from the alcohol (I) only by loss of hydrogen as well as water, and dehydrogenation accompanying cyclodehydration by the latter reagent is rare (cf. Cook, Ludwiczak, and Schoental, *J.*, 1950,

1112; Burr, Riefel, Kubico, and Gold, *J. Amer. Chem. Soc.*, 1948, **70**, 1073). However, the ultraviolet spectrum of the hydrocarbon (Fig. 1) confirms the structure assigned by Rapson; and it is certainly formed from the alcohol (I), and not from an impurity, since

FIG. 1. *Ultraviolet spectra of Rapson's hydrocarbon (c), naphthalene (a), and 1 : 2 : 3 : 4-tetrahydrophenanthrene (b), in 95% ethanol.*

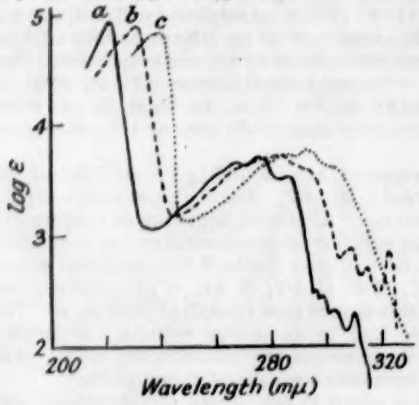


FIG. 4. *Ultraviolet spectra of phenanthrene (a) and the phenanthrene derivative (VI), in cyclohexane.*

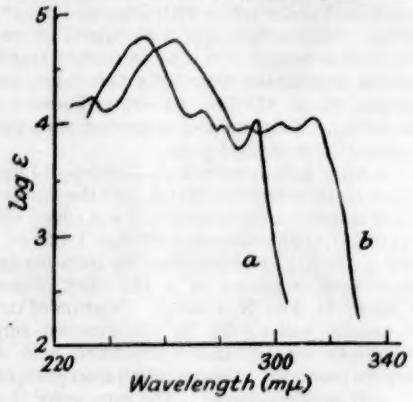


FIG. 2. *Ultraviolet spectra of the spiran (III) (a) and perinaphthene (b), in cyclohexane.*

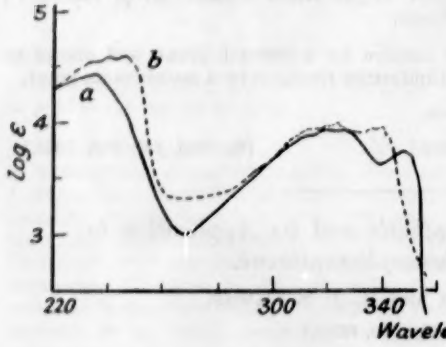
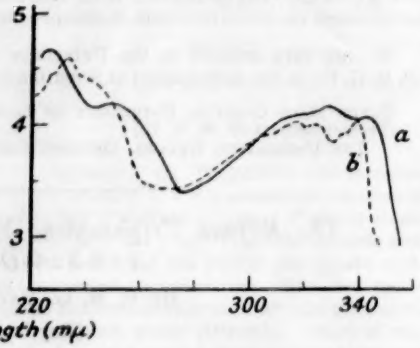
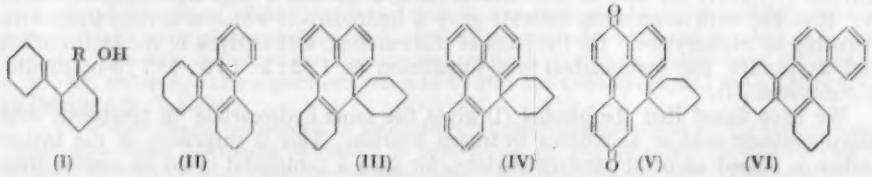


FIG. 3. *Ultraviolet spectra of the spiran (IV) (a) and benzanthrene (b), in cyclohexane.*



we have now obtained the alcohol crystalline and converted the pure material into the same hydrocarbon.

Polyphosphoric acid also catalysed the cyclodehydration of *cyclo*hexanone to dodecahydrotriphenylene (cf. Mannich, *Ber.*, 1907, **40**, 163) and, although the yield was poor, this provides a convenient route to triphenylene.



(I) (II) (III) (IV) (V) (VI)

We then attempted to apply the Rapson synthesis to the preparation of 1 : 2-3 : 4-dibenzophenanthrene, by cyclisation of 2-*cyclo*hex-1′-enyl-1-1′-naphthyl*cyclo*hexanol

(I; R = 1-naphthyl). Ring closure with aluminium chloride or anhydrous hydrogen fluoride gave a hydrocarbon formed by loss of water only; but this appeared to be the spiran (III) since its ultraviolet spectrum closely resembled that of perinaphthene (Fig. 2). Dehydrogenation of the spiran gave, as expected, a hydrocarbon with an empirical formula corresponding to that of *cyclo*hexane*spiro*-7-benzanthrene (IV) and an ultraviolet spectrum very similar to that of benzanthrene (Fig. 3). Oxidation of the spiran (IV) gave a crimson quinone for which the structure (V) seems the most probable.

Cyclisation of 2-*cyclo*hex-1′-enyl-1-2′-naphthyl*cyclo*hexanol (I; R = 2-naphthyl) with aluminium chloride gave a small yield of the octahydro-1 : 2-3 : 4-di*cyclo*hexenophenanthrene (VI) which was smoothly dehydrogenated to the known 1 : 2-3 : 4-dibenzophenanthrene. The structure of the precursor (VI) follows from the resemblance of its spectrum to that of phenanthrene (Fig. 4).

Experimental

2-cyclo*Hex*-1′-*enyl*-1-*phenyl*cyclo*hexanol.*—The alcohol prepared by Rapson's method (*loc. cit.*) was fractionated. The fraction, b. p. 158—161°/1·25 mm., solidified during five weeks and then crystallised from light petroleum (b. p. 40—60°) in prisms, m. p. 59—60° (Found: C, 84·3; H, 9·5. Calc. for $C_{18}H_{24}O$: C, 84·3; H, 9·4%).

Octahydrotriphenylene.—(a) *With anhydrous hydrogen fluoride.* The preceding alcohol (22·5 g.) was dissolved in anhydrous hydrogen fluoride and left overnight. The residue after evaporation of the hydrogen fluoride was treated with picric acid (10 g.) in ethanol, giving octahydrotriphenylene picrate (6 g.), m. p. 196—197°, raised to 198° by recrystallisation from benzene (Rapson, *loc. cit.*, gives m. p. 185°). Octahydrotriphenylene was isolated by passing a solution of the picrate in benzene through an alumina column; it crystallised from ethanol, acetic acid, or light petroleum in needles, m. p. 125·5° (Rapson, *loc. cit.*, gives m. p. 129—130°; Bachmann and Struve, *J. Org. Chem.*, 1939, **4**, 472, give m. p. 120·5—122°) [Found: C, 91·4; H, 8·6. Calc. for $C_{18}H_{22}$: C, 90·7; H, 9·3. Calc. for $C_{18}H_{20}$ (II): C, 91·6; H, 8·5%].

(b) *With polyphosphoric acid.* The alcohol (10 g.) was added to a stirred solution of phosphoric oxide (25 g.) in syrupy phosphoric acid (60 ml.) at 110—120°. After 1 hr., water was added, and the octahydrotriphenylene isolated as its picrate (1·4 g.), m. p. 193—196°.

Modified Mannich Synthesis of Triphenylene.—*cyclo*Hexanone (100 ml.) and polyphosphoric acid (400 ml.) were heated together at 160° for 12 hr. The mixture was cooled and poured on ice. The dark, very viscous oil which separated was isolated with chloroform and fractionated. The fraction, b. p. 180—210°/1·5 mm. (27 g.), partly solidified, and after crystallisation from ethanol formed needles, m. p. 210—220°. This impure dodecahydrotriphenylene was dehydrogenated over palladised charcoal at 340—360°; the product crystallised from toluene, to give triphenylene as brownish needles (1·2 g.), m. p. 194—197°. Purification by vacuum-sublimation or chromatography, followed by a further crystallisation, then gave colourless needles, m. p. 199°.

2-cyclo*Hex*-1′-*enyl*-1-1′-*naphthyl*cyclo*hexanol.*—Prepared in the same manner as the phenyl analogue (Rapson, *loc. cit.*), the alcohol was collected at 168—172°/0·4 mm. as an uncrystallisable gum (Found: C, 87·8; H, 8·65. Calc. for $C_{22}H_{26}O$: C, 86·2; H, 8·55%) and apparently contained a hydrocarbon impurity, formed by dehydration, judging by analysis of a fraction, b. p. 180—182°/0·4 mm. (Found: C, 91·0; H, 8·4. Calc. for $C_{22}H_{24}$: C, 91·6; H, 8·4%).

8 : 9 : 10 : 11-*Tetrahydro*cyclo*hexane*spiro-7-*benzanthrene.*—Cyclisation of the foregoing alcohol (61 g.) with aluminium chloride (55 g.) in carbon disulphide (100 ml.) following Rapson's procedure (*loc. cit.*), gave a series of fractions, b. p. 200° to 265° at 5 mm., all of which formed the same derivatives. The *trinitrobenzene adduct* of the spiran (III) crystallised from ethanol in red needles, m. p. 176° (Found: C, 67·1; H, 5·4; N, 8·3. $C_{28}H_{25}O_6N_3$ requires C, 67·3; H, 5·05; N, 8·4. $C_{28}H_{27}O_6N_3$ requires C, 67·1; H, 5·4; N, 8·4%). The *picrate* crystallised from ethanol in purple-brown needles, m. p. 163—164° (Found: C, 65·2; H, 5·5; N, 8·2. $C_{28}H_{25}O_7N_3$ requires C, 65·2; H, 4·9; N, 8·15. $C_{28}H_{27}O_7N_3$ requires C, 65·0; H, 5·3; N, 8·1%). Decomposition of the picrate with alkali gave the *spiran* (III) which crystallised from light petroleum in colourless prisms, m. p. 98° (Found: C, 91·5; H, 8·5. $C_{22}H_{24}$ requires C, 91·6; H, 8·4%). The same product was formed when the alcohol was treated with anhydrous hydrogen fluoride.

cyclo*Hexane*spiro-7-*benzanthrene* (IV).—The foregoing tetrahydro-compound (1·5 g.) was dehydrogenated over palladised charcoal at 320°. Crystallisation of the product from light petroleum (b. p. 100—120°) gave the *spiran* (IV) as prisms, m. p. 88—89° (1·2 g.), raised to

89—90° by recrystallisation from ethanol (Found : C, 93·0; H, 7·3. $C_{22}H_{20}$ requires C, 92·9; H, 7·1%). The *picrate* crystallised from ethanol in bright red needles, m. p. 141—142° (Found : C, 65·3; H, 4·9; N, 8·0. $C_{28}H_{23}O_7N_3$ requires C, 65·5; H, 4·5; N, 8·2%).

cyclo*Hexane*spiro-7-*benzanthrene*-3 : 9-*quinone* (V).—The hydrocarbon (IV) (0·5 g.) was boiled with acetic acid (10 ml.) and potassium dichromate (2 g.) for 10 min. The solution was poured into ice-water, and the precipitate collected, washed, and dried (0·4 g.). The *quinone* (0·4 g.) crystallised from acetic acid in crimson plates, m. p. 221—222° (Found : C, 83·6; H, 5·9; $C_{22}H_{16}O_2$ requires C, 84·05; H, 5·8%); it did not form an azine with *o*-phenylenediamine.

2-cyclo*Hex*-1′-*enyl*-1-2′-*naphthyl*cyclo*hexanol*.—2-Naphthylmagnesium bromide was prepared from 2-bromonaphthalene (40·4 g.) and magnesium turnings (6 g.) in anhydrous ether (200 ml.). Dry benzene (300 ml.) was then added, followed by *cyclo*hexenyl*cyclo*hexanone (35 g.). The mixture was left overnight and the product then decomposed by the addition of ice and ammonium chloride. The ether layer was distilled, giving the *alcohol* (20·6 g.), b. p. 200—202°/0·4 mm. (Found : C, 87·4; H, 8·3. $C_{22}H_{26}O$ requires C, 86·2; H, 8·55%).

1 : 2-3 : 4-*Di*cyclo*hexenophenanthrene* (VI).—The foregoing alcohol (20·6 g.) in carbon disulphide (50 ml.) was added with shaking to powdered aluminium chloride (18·5 g.) in carbon disulphide (50 ml.). After 12 hr. at room temperature ice and hydrochloric acid were added, the carbon disulphide distilled off, di*cyclo*hexenophenanthrene isolated with chloroform, distilled under reduced pressure, and converted into the *picrate* which crystallised from ethanol, benzene, or light petroleum in dark red needles, m. p. 172°, depressed to 144—150° on admixture with the picrate of tetrahydro*cyclo*hexane*spiro*-7-benzanthrene (Found : C, 65·2; H, 4·5; N, 8·0. $C_{28}H_{25}O_7N_3$ requires C, 65·2; H, 4·9; N, 8·15%). The *hydrocarbon*, isolated by passing a solution of the picrate in benzene through an alumina column, crystallised from light petroleum in white prisms, m. p. 115—116° (Found : C, 92·7; H, 7·3. $C_{22}H_{22}$ requires C, 92·3; H, 7·7%). The trinitrobenzene adduct crystallised from light petroleum in orange needles, m. p. 173°.

1 : 2-3 : 4-*Dibenzophenanthrene*.—Dehydrogenation of the di*cyclo*hexeno-compound gave 1 : 2-3 : 4-dibenzophenanthrene which crystallised from light petroleum in colourless needles, m. p. 115—116° (lit., 115—116°). The picrate crystallised from light petroleum in orange needles, m. p. 139—139·5° (lit., 140—140·5°). The trinitrobenzene adduct crystallised from benzene in yellow needles, m. p. 167°. Oxidation with chromic acid gave the quinone, crystallising from acetic acid in crimson needles, m. p. 232—236° (lit., 237—238°; 238—240°).

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The Monosubstitution of Triphenylene.

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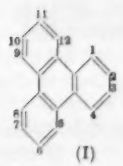
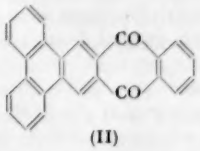
The orientations of the products obtained by mononitrating and by monobrominating triphenylene have been established, and the results are discussed in the light of the predicted reactivity of the triphenylene molecule.

The symmetry of the triphenylene molecule (I) limits the number of its isomeric monosubstituted derivatives to two, those with substituents at $C_{(1)}$ or $C_{(2)}$, and the former of these atoms is predicted to be slightly the more reactive. Thus, Dewar (*J. Amer. Chem. Soc.*, 1952, **74**, 3358) gives localisation energies of 2·02β and 2·12β for $C_{(1)}$ and $C_{(2)}$, respectively, and the mobile bond orders calculated by Coulson, Berthier, Greenwood, and Pullman (*Compt. rend.*, 1948, **226**, 1906) lead to free valencies of 0·439 and 0·405 for the same atoms, respectively. The simple method, which assumes the stability of the transition state to be proportional to the number of classical ionic structures written with a charge on the carbon in question, gives 23 such structures with a charge on $C_{(1)}$, and 22 with a charge on $C_{(2)}$, again predicting slightly greater reactivity for $C_{(1)}$. But $C_{(1)}$ is subjected to considerable steric hindrance from the hydrogen atom at position 12, and the effect of this

factor on the course of substitution was therefore examined. The situation is analogous to that obtaining in naphthalene, where, however, the steric factor is much smaller, and the difference in reactivity between $C_{(1)}$ and $C_{(2)}$ is much greater.


(I)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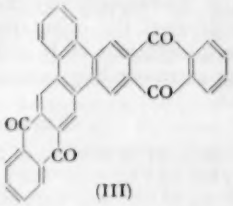
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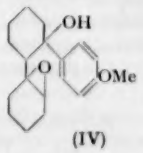
(IV)

Phthalic anhydride and triphenylene in the presence of aluminium chloride give 2-*o*-carboxybenzoyltriphenylene, and this acid cyclises only at the less hindered 3-position to give the quinone (II) (Clar, *Ber.*, 1948, **81**, 68). The condensation of one molecule of the hydrocarbon with two of phthalic anhydride yields a mixture of two, or all, of the isomeric 2 : 6-, 2 : 7-, and 2 : 11-di-*o*-carboxybenzoyltriphenylenes, and this mixture also cyclises only at the less hindered positions since a single diquinone (III) is formed (Clar, *J.*, 1949, 2440). Similarly, acetyl chloride gives 2-acetyltriphenylene (Buu-Hoï and Jacquignon, *J.*, 1953, 941), oxalyl chloride gives triphenylene-2-carboxylic acid (Cook and Hewitt, *J.*, 1933, 404; Buu-Hoï *et al.*, *loc. cit.*), and carbamoyl chloride gives triphenylene-2-carboxyamide (I.G. Farbenind. A.-G., F.P. 797,072/1936).

It is also claimed that suphonation takes place at position 2 (Schmelzer, D.R.-P. 654,283/1937). This is now established by comparing the hydroxy-compound obtained from the sulphonic acid by caustic fusion (Schuster, Broich, and Schmelzer, D.R.-P. 623,651/1936), with synthetic material obtained from 2-(1 : 2-epoxy*cyclo*hexyl)-1-*p*-methoxyphenyl*cyclo*hexan-1-ol (IV) by cyclisation and demethylation with a mixture of acetic and hydrobromic acid, followed by dehydrogenation with palladised charcoal. This method of synthesising triphenylene derivatives is an improvement of Rapson's method (*J.*, 1941, 15), and its applications will be discussed in a later paper.

The course of sulphonation and acylation reactions is, however, particularly sensitive to steric factors, and nitration and bromination of triphenylene were therefore examined. Trinitration of triphenylene has been described by Mannich (*Ber.*, 1907, **40**, 162), and it is difficult to restrict the reaction to mononitration, but by heating the hydrocarbon in acetic anhydride with the theoretical amount of nitric acid, 27% and 23% yields of 1- and 2-nitrotriphenylene, respectively, have now been obtained. No appreciable amount of dinitrophenylene was formed, but oxidation of the starting material occurred. These yields are consistent with the predicted reactivities of $C_{(1)}$ and $C_{(2)}$, and they contrast with the exclusively 2-substitution occurring in the reactions previously reported.

The bromination of triphenylene by one mol. of bromine in carbon disulphide containing iron has been described by Schuster and Broich (D.R.-P. 650,058/1937); the product is now shown to be a mixture of bromo- and dibromo-triphenylene, from which 2-bromotriphenylene, m. p. 128—132°, was obtained chromatographically in 56% yield; the pure compound has m. p. 132—133°. No 1-bromotriphenylene could be isolated, but complete resolution of the product into its components was not achieved, and a synthetic mixture of 1- and 2-bromotriphenylene containing 10% of the former could not be separated. It is clear, however, that 1-bromotriphenylene, if formed at all, is formed in much smaller amounts than the 2-isomer. This is attributed to steric hindrance of $C_{(1)}$, coupled with the larger effective size of the bromine atom.

To establish the orientation of the nitro- and bromo-triphenylenes, 2-aminotriphenylene was prepared from the 2-acetyl compound through the intermediate stages of carboxylic acid, carbonyl chloride, and azide. By use of nitrobenzene as a solvent in the preparation of 2-acetyltriphenylene, instead of the excess of acetyl chloride used by Buu-Hoï *et al.* (*loc. cit.*), the yield was improved from 50% to 88·5%, and the yield of amine amounted to 39% (on triphenylene). Attempts to convert triphenylene-2-carboxyamide into the

amine by means of aqueous sodium hypobromite failed because of the insolubility of the amide, but methanolic sodium hypobromite gave methyl *N*-2-triphenylenylcarbamate which was hydrolysed subsequently to the amine, the yield amounting to only 8% (on amide). Conversion of 2-aminotriphenylene into the 2-hydroxy-compound by means of the diazo-reaction confirmed the orientation given to 2-acetyltriphenylene previously (*idem, loc. cit.*). The orientations of 1- and 2-nitrotriphenylene were then established by reducing them to the corresponding amines, which yielded 1- and 2-bromotriphenylene by the diazo-reaction.

Experimental

2-Hydroxytriphenylene.—(*a*) A mixture of 2-*cyclo*hex-1′-enyl-1-*p*-methoxyphenyl*cyclo*hexan-1-ol (6 g.; cf. Rapson, *loc. cit.*) in ether (50 c.c.) and monoperphthalic acid (4·6 g.) in ether (65 c.c.) was kept at 0° for 16 hr., then washed with aqueous sodium hydrogen carbonate and dried (Na_2SO_4), and the ether removed. The residual pale yellow, viscous liquid (6·3 g.) was dissolved in boiling acetic acid (63 c.c.), hydrobromic acid (34% w/v; 44 c.c.) was added, the mixture was refluxed for 24 hr., cooled, and diluted with water, and the product extracted with benzene. The benzene solution was washed with sodium hydrogen carbonate and dried (Na_2SO_4), the benzene was removed, and then the residue (5·4 g.) was heated with palladised charcoal (30% Pd; 0·54 g.) in a stream of nitrogen for 4 hr. at 300°. The product was sublimed at 200—220° (bath)/10^{-2} mm., the sublimate was extracted with a solution of potassium hydroxide in aqueous methanol, the extract was acidified, and the resulting precipitate was crystallised from chlorobenzene, giving 2-hydroxytriphenylene as white needles, m. p. 215—217°. Rapson (*loc. cit.*) gives m. p. 213—215°; Schuster *et al.* (*loc. cit.*) give m. p. 216—219°.

(*b*) Sodium triphenylene-2-sulphonate was prepared from triphenylene (70% yield) and converted into crude 2-hydroxytriphenylene (72% yield), m. p. 198—200°, by the processes of Schmelzer and of Schuster *et al.* (*locc. cit.*), respectively. Sublimation of this product, followed by two crystallisations from chlorobenzene, gave pure 2-hydroxytriphenylene (27% on sulphonic acid), m. p. 221°, mixed m. p. with material from (*a*) 217—219° (Found: 87·6; H, 5·1. Calc. for $C_{18}H_{12}O$: C, 88·5; H, 5·0%). Under ultraviolet light it showed a blue fluorescence which became bright apple-green on addition of alkali. The *picrate* formed orange needles (from ethanol), m. p. 224—225° (decomp.) (Found: N, 9·0. $C_{24}H_{15}O_8N_3$ requires N, 8·9%). Methyl sulphate and sodium hydroxide gave the methyl ether, m. p. 119° (from light petroleum) (Found: C, 88·8; H, 5·4. Calc. for $C_{19}H_{14}O$: C, 88·4; H, 5·5%). Rapson (*loc. cit.*) gives m. p. 97—98°. The acetyl derivative had m. p. 130°; Rapson (*loc. cit.*) gives m. p. 129°.

(*c*) By boiling an aqueous suspension of triphenylene-2-diazonium chloride until it no longer coupled with R-salt, and then subliming the dried product and thrice crystallising the picrate of the sublimate from ethanol, 2-hydroxytriphenylene picrate was obtained, m. p. and mixed m. p. 220—223° (Found: N, 8·6%).

2-Acetyltriphenylene.—Acetyl chloride (1·75 g.) was added at 0° to a solution of triphenylene (5·0 g.) in nitrobenzene (40 c.c.) containing aluminium chloride (3·5 g.). The mixture was kept at room temperature for 20 hr., and at 40° for a further 4 hr., and then poured into dilute hydrochloric acid at 0°. The nitrobenzene was removed by steam-distillation, and the dried product was sublimed at 160—180° (bath)/10^{-2} mm. Crystallisation of the sublimate from acetic acid gave 2-acetyltriphenylene (5·25 g.), m. p. 150—152°, recrystallisation from ethanol raising this m. p. to 152—153°. Buu-Hoï *et al.* (*loc. cit.*) give m. p. 152°.

Triphenylene-2-carboxylic Acid.—Oxidation of 2-acetyltriphenylene (10 g.) in dioxan (180 c.c.) at 60° for 1 hr. with a solution of bromine (24 g.) in water (180 c.c.) containing sodium hydroxide (24 g.) gave the acid (8·3 g.), m. p. 336—338° (from pentyl alcohol) (Found: C, 83·6; H, 4·6. Calc. for $C_{19}H_{12}O_2$: C, 83·8; H, 4·4%). Buu-Hoï *et al.* (*loc. cit.*), and Cook *et al.* (*loc. cit.*), give m. p. 325—326°. Diazomethane in ether and the acid in dioxan gave the methyl ester, m. p. 171—172° (from ethanol) (Found: C, 83·7; H, 5·1. Calc. for $C_{20}H_{14}O_2$: C, 83·9; H, 4·9%). Cook *et al.* (*loc. cit.*), give m. p. 122—124°. Thionyl chloride, purified by distillation from quinoline, converted the acid into the pale yellow *acid chloride* (90% yield), m. p. 130—131° (from light petroleum) (Found: Cl, 12·3. $C_{19}H_{11}OCl$ requires Cl, 12·2%). Concentrated aqueous ammonia converted the chloride almost quantitatively into the *amide*, m. p. 292—293° (from pyridine) (Found: C, 83·5; H, 5·2; N, 5·3. $C_{19}H_{13}ON$ requires C, 84·2; H, 4·8; N, 5·2%). By addition of sodium azide (0·5 g.) in water (2·0 c.c.) to the acid chloride (1·8 g.) in dioxan (20 c.c.) at 0°, followed, after 15 min., by the addition of water (25 c.c.), the *azide* (1·8 g.) was obtained (m. p. 135°). Decomposition of this material (0·30 g.) in toluene gave nitrogen (22·4 c.c.); the azide requires 22·6 c.c.

Benzyl alcohol and the acid azide gave *benzyl* N-2-*triphenylenylcarbamate*, m. p. 169—170° (from light petroleum) (Found: N, 3·6. $C_{26}H_{19}O_2N$ requires N, 3·7%), which failed to give 2-aminotriphenylene when heated at 140° with acetic and concentrated hydrochloric acid.

1- *and* 2-*Nitrotriphenylene*.—Nitric acid (70% w/w; 1·67 c.c.) was added during 45 min. to triphenylene (6·0 g.) in acetic anhydride (330 c.c.) at 60°, and the mixture was kept at 60° for a further 4 hr. Decomposition of the anhydride with an excess of water at room temperature yielded a brown solid which was dissolved in benzene. This solution was washed with aqueous sodium hydrogen carbonate, dried (Na_2SO_4), and chromatographed on alumina (265 × 40 mm.) with benzene as eluant, giving: F_1, triphenylene (0·23 g.); F_2, clean yellow gum (5·68 g.); F_3, dark-brown gum (0·23 g.). Chromatography of F_2 in benzene on alumina (650 × 27 mm.) gave two well-defined yellow bands, the lower of which yielded 1-*nitrotriphenylene* (1·96 g.), m. p. 165—168·5°, raised by crystallisation from acetic acid to m. p. 168·5—169·5° (Found: N, 5·2. $C_{18}H_{11}O_2N$ requires N, 5·1%). The upper band yielded 2-*nitrotriphenylene* (1·63 g.), m. p. 163—165°, raised by crystallisation from acetic acid to m. p. 165·5—166° (Found: N, 5·3%).

2-*Aminotriphenylene*.—(*a*) A mixture of 2-azidotriphenylene (3·5 g.), concentrated hydrochloric acid (100 c.c.), and acetic acid (100 c.c.) was refluxed for 7 hr., and then basified with ammonia. The dried precipitate was sublimed at 170—180° (bath)/10^{-2} mm., the sublimate was repeatedly extracted with boiling, dilute hydrochloric acid, and the resulting solution was basified with ammonia, giving 2-*aminotriphenylene* (1·74 g.), m. p. 140—140·5° (from ethanol) (Found: C, 88·8; H, 5·4; N, 5·6. $C_{18}H_{13}N$ requires C, 88·9; H, 5·4; N, 5·8%). The N-*acetyl* derivative formed needles, m. p. 257—258° (from acetic acid, and ethanol, successively) (Found: C, 84·0; H, 5·0; N, 4·9. $C_{20}H_{15}ON$ requires C, 84·2; H, 5·3; N, 4·9%).

(*b*) Bromine (0·30 g.) was added to triphenylene-2-carboxyamide (0·9 g.) in methanol (30 c.c.) containing sodium methoxide (0·40 g.), and the mixture was kept at 50° for 15 min., cooled, and acidified with acetic acid, and the methanol was removed by distillation. The residue, twice crystallised from light petroleum (b. p. 80—100°), yielded pale yellow *methyl* N-2-*triphenylenylcarbamate* (0·35 g.), m. p. 188—189° (Found: C, 79·4; H, 5·0; N, 4·8. $C_{20}H_{15}O_2N$ requires C, 79·8; H, 5·0; N, 4·7%). A mixture of this urethane (0·40 g.), concentrated hydrochloric acid (20 c.c.), and acetic acid (10 c.c.) was refluxed for 24 hr., basified with ammonia, and worked up as described in (*a*), giving 2-aminotriphenylene (0·07 g.).

1-*Aminotriphenylene*.—Hydrogen chloride was passed for 2·5 hr. into a boiling mixture of acetic acid (28·5 c.c.) and concentrated hydrochloric acid (1·5 c.c.) containing granulated tin (3·5 g.) and 1-nitrotriphenylene (1·96 g.). The mixture was then basified and extracted with ether, the ether was dried (Na_2SO_4), and hydrogen chloride was passed in. The precipitate was basified, removed in ether, and sublimed at 170—180° (bath)/10^{-2} mm., yielding 1-*aminotriphenylene* (0·94 g.), m. p. 96—101°, raised to m. p. 103—104° by crystallisation from ethanol (Found: N, 5·4%).

2-*Bromotriphenylene*.—(*a*) A solution of 2-aminotriphenylene (0·25 g.) in acetic acid (2·0 c.c.) was poured into 20% hydrobromic acid (5 c.c.), thus precipitating the amine hydrobromide which was diazotised at 0° by addition of sodium nitrite (0·070 g.) in water (2 c.c.). The diazonium salt separated, and the resulting paste was added to cuprous bromide (1·2 g.) in 40% hydrobromic acid (6 c.c.), and then the mixture was boiled for 30 min. The dried product was sublimed at 160—180° (bath)/10^{-2} mm., and, after passage in light petroleum through a short alumina column, followed by crystallisation from light petroleum, gave 2-*bromotriphenylene* (0·10 g.), m. p. 131—132° (Found: C, 70·1; H, 3·5; Br, 26·1. $C_{18}H_{11}Br$ requires C, 70·4; H, 3·6; Br, 26·0%).

(*b*) Bromine (1·40 g.) was added at 20° to a stirred solution of triphenylene (2·00 g.) in carbon disulphide (88 c.c.) contained iron powder (0·09 g.). Stirring was continued for 72 hr., at the end of which the mixture was filtered, the filtrate was washed with aqueous sodium hydrosulphite (dithionite), and then with water, and dried (Na_2SO_4), and the carbon disulphide was removed. The residue was chromatographed on alumina (460 × 27 mm.) with light petroleum (b. p. 60—80°) as eluant, and the first 3220 c.c. of eluate yielded 2- bromotriphenylene (1·49 g.), m. p. 128—132°, raised to m. p. 132—133° by crystallisation from acetone. The mixed m. p. with material from (*a*) was 131—133°. Subsequent eluates gave residues with bromine contents increasing to a maximum of 39%, and no pure compound was isolated from them. Elution with light petroleum–benzene gave inferior separation.

The Department of Chemistry, The University, Hull. [*Received, June 22nd*, 1955.]

Absorption Spectra of Nitro- and Fluoro-derivatives of Phenanthrene, Triphenylene, and Pyrene.

By P. M. G. Bavin and M. J. S. Dewar.

[Reprint Order No. 6654.]

During experiments to provide quantitative data on reactivity in aromatic substitution reactions we synthesised all the mononitro-derivatives of phenanthrene and triphenylene (Bavin and Dewar, *J.*, 1955, 4479). Professor H. C. Longuet-Higgins asked us to prepare, from the available amines *via* the diazonium fluoroborates, the corresponding fluoro-compounds and determine their absorption spectra, for comparison with a general theory of substituent effects on light absorption which he and Mr. J. N. Murrell had developed. The Table records the spectra [wavelengths of absorption maxima in mμ, intensites (in parentheses) as $\log_{10} \epsilon_{max.}$] of the fluoro- and mononitro-derivatives and also of 1-nitro- and 1-fluoro-pyrene. As the spectra of the nitro- and fluoro-benzenes and -naphthalenes are known, these results provide a good range of comparable data for the testing of theories of light absorption. For complete spectra see Bavin (Ph.D. Thesis, London, 1954).

Fluorophenanthrenes.

1-	2-	3-	4-	9-
246 (4·67)	—	—	—	—
253·5 (4·78)	250 (4·82)	249·5 (4·77)	247·5 (4·96)	248—250 (4·73)
—	265·5 (4·18)	269 (4·19)	267·5 (4·04)	269 (4·15)
275 (4·08)	275·5 (4·15)	274·5 (4·20)	274 (4·03)	275 (4·11)
283·5 (4·02)	282 (4·04)	280·5 (4·06)	285 (4·11)	284·5 (3·95)
295·5 (4·17)	294 (4·09)	292·5 (4·05)	296·5 (4·27)	296·5 (4·01)
317·5 (2·72)	315 (2·56)	318 (2·79)	318 (2·70)	317·5 (2·62)
326 (2·62)	322 (2·44)	325·5 (2·68)	326 (2·66)	325 (2·54)
332·5 (3·04)	330 (2·65)	333·5 (3·04)	332 (3·04)	332·5 (2·85)
341·5 (2·61)	337 (2·35)	341·5 (2·65)	341·5 (2·64)	340·5 (2·54)
348·5 (3·14)	346 (2·49)	349·5 (3·16)	348 (3·11)	348·5 (2·93)

Nitrophenanthrenes.

1-	2-	3-	4-	9-
240 (4·71)	238·5 (4·15)	245 (4·84)	221 (4·37)	248·5 (4·66)
298·5 (3·98)	267·5 (4·63)	262 (4·67)	240 (4·62)	290 (3·98)
	276 (4·67)	266 (4·65)	278 (4·09)	332 (3·82)
	292 (4·26)	295·5 (3·90)	298·5 (3·98)	
	312 (4·10)	335 (4·03)		
	361 (3·15)			

Fluorotriphenylenes.		*Nitrotriphenylenes.*		1-*Fluoropyrene*	1-*Nitropyrene.*
1-	2-	1-	2-		
252 (5·01)	249 (4·95)	243 (5·46)	243·5 (5·12)	232 (4·61)	233 (4·61)
259·5 (5·18)	258 (5·18)	244 (5·46)	251·5—2 (5·08)	241 (4·88)	285 (4·18)
274·5 (4·33)	273 (4·26)	—	274·5 (5·04)	252·5 (4·06)	313 (3·70)
287 (4·29)	284 (4·20)	249 (5·51)	309·5 (4·40)	263 (4·37)	—
—	304 (3·42)	255 (5·54)	334·5 (4·36)	273·5 (4·66)	372—3 (4·12)
316·5 (2·83)	314·5 (2·88)			307·5 (4·01)	—
324·5 (2·69)	321·5 (2·77)			321 (4·39)	392 (4·07)
331 (3·00)	329·5 (2·95)			338 (4·57)	—
338·5 (2·60)	336·5 (2·72)			356 (3·32)	408 (3·99)
347 (2·93)	345 (2·95)			367·5 (2·87)	
				375 (3·48)	

Experimental.—The diazonium fluoroborates were refluxed in light petroleum (b. p. 100—120°) for 30 min. By chromatography in light petroleum on alumina, followed by sublimation *in vacuo* and recrystallisation, were obtained in good yield : 1-*fluorophenanthrene*, blades, m. p. 100° (from light petroleum) (Found : C, 85·9; H, 4·9. $C_{14}H_9F$ requires C, 85·6; H, 4·6%); 2-*fluorophenanthrene*, plates, m. p. 104—105° (from light petroleum or methanol) (Found : C, 86·0; H, 4·8%); 3-*fluorophenanthrene*, plates, m. p. 84° (from methanol) (Found : C, 85·7; H, 4·8%); 4-*fluorophenanthrene*, white needles, m. p. 47° (from methanol) (Found : C, 86·0; H, 4·7%); 9-fluorophenanthrene, prisms, m. p. 51·2° (lit., 51—52°) (from light petroleum), and 1-*fluoropyrene*, long white needles (m. p. 136°) (from light petroleum) (Found : C, 87·9; H, 4·4.

$C_{16}H_9F$ requires C, 87·3; H, 4·1%). The *picrate* of the last crystallised from ethanol or acetic acid in blood-red needles, m. p. 208—210° (Found: N, 9·45. $C_{22}H_{12}O_7N_3F$ requires N, 9·35%).

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QUEEN MARY COLLEGE, UNIVERSITY OF LONDON. [*Received, July 28th*, 1955.]

The Degradation of Quaternary Ammonium Salts. Part IX. Demonstration of the Strictly Intramolecular Character of a Rearrangement.*

By R. A. W. JOHNSTONE and T. S. STEVENS.

[Reprint Order No. 6601.]

THE rearrangement (Stevens *et al.*, *J.*, 1928, 3193; 1930, 2107) of dialkylbenzylphenacylammonium bromides (I) to α-dialkylamino-ketones (III) seems to proceed *via* an intermediate zwitterion (II).

$$\underset{\text{(I)}}{Ph\cdot CO\cdot CH_2\cdot \overset{+}{N}R_1R_2\,\overset{-}{Br}\,\atop CH_2Ph} \xrightarrow{\bar{O}H} \underset{\text{(II)}}{Ph\cdot CO\cdot \bar{C}H\cdot \overset{+}{N}R_1R_2\,\atop CH_2Ph} \longrightarrow \underset{\text{(III)}}{Ph\cdot CO\cdot CH(CH_2Ph)\cdot NR_1R_2}$$

In the rearrangement of a mixture of two quaternary salts no interchange of migrating groups could be detected, but this demonstration of the intramolecular character of the change was incomplete, since barely 80% of the initial material consumed was accounted for. Hauser and Kantor (*J. Amer. Chem. Soc.*, 1951, **73**, 1437) likewise concluded that the reaction was intramolecular and that the migrating radical did not migrate as an ion. This was largely confirmed by the observation (Campbell, Houston, and Kenyon, *J.*, 1947, 93; Brewster and Kline, *J. Amer. Chem. Soc.*, 1952, **74**, 5179) that optically active dimethylphenacyl-1-phenylethylammonium bromide is rearranged with 97% retention of the configuration of the active centre. The American authors inferred that the reaction was an intramolecular type of nucleophilic displacement and that the radical did not move as an ion. The same data are accommodated by Dewar's description (*Ann. Reports*, 1951, **48**, 127; *Bull. Soc. chim. France*, 1951, C71) of the reaction in terms of the molecular-orbital π-complex theory as involving the migration of a positively charged radical which does not escape from the molecule at any time.

Very complete evidence for the intramolecular nature of the reaction has now been obtained by the use of benzyl-*p*-bromophenacyldimethylammonium bromide (IV) in which the migrating benzyl group is radioactively labelled with ^{14}C. A mixture of this compound with benzyldimethylphenacylammonium bromide (V) whose rates of rearrangement are in the ratio 0·8 : 1 (Thomson and Stevens, *J.*, 1932, 55) was treated with alkali.

$$\underset{\text{(IV)}}{p\text{-}Br\cdot C_6H_4\cdot CO\cdot CH_2\cdot \overset{+}{N}Me_2\,\overset{-}{Br}\,\atop {}^{14}CH_2Ph} \xrightarrow{\bar{O}H} \underset{\text{(VI)}}{Br\cdot C_6H_4\cdot CO\cdot CH(CH_2Ph)\cdot NMe_2}$$

$$\underset{\text{(V)}}{Ph\cdot CO\cdot CH_2\cdot \overset{+}{N}Me_2\,\overset{-}{Br}\,\atop CH_2Ph} \xrightarrow{\bar{O}H} \underset{\text{(VII)}}{Ph\cdot CO\cdot CH(CH_2Ph)\cdot NMe_2}$$

The tertiary amines (VI) and (VII) were separated and no radioactivity appeared in (VII), showing that there had been no interchange of migrating groups.

In the synthesis of the bromide (IV), radioactive formaldehyde was used to chloromethylate benzene (Blanc, *Bull. Soc. chim. France*, 1923, **33**, 313) and the resulting benzyl chloride converted successively into benzyldimethylamine and (IV) On the small scale, conditions for obtaining good yields in the chloromethylation were critical.

Experimental.—A solution of the salts (IV) and (V) (200 mg. of each) in a slight excess of 0·1N-sodium ethoxide was kept at 50° for 48 hr. (ample time for complete reaction). Water

* Part VIII, *J.*, 1934, 279.

was added and the precipitated bases were extracted with ether. The combined ethereal extracts were treated with 2N-sulphuric acid (5 ml.), and the acid solution was heated to about 50°. 10N-Hydrochloric acid (10 ml.) was added and the solution left to cool in ice. Most of the hydrochloride of the base (VI) separated together with a little of that of (VII). The free base (VI), crystallised from ethanol, melted at 104°, alone or mixed with a non-radioactive specimen. The remaining acid solution was made basic and the precipitated base (VII) was recrystallised three times from ethanol [to ensure the absence of radioactive contamination by small amounts of (VI)]; its m. p., 77—78°, was not depressed by admixture with an authentic specimen.

Samples of the compounds (IV), (VI), and VII) were matted on small metal planchettes. The degree of radioactivity in each sample was measured, at infinite thickness, by a Geiger–Müller end-window counter, giving the following results :

Sample	None	(IV)	(VI)	(VII)
Counts min.$^{-1}$ cm.$^{-2}$	16	373	403	13

Preparation of benzyl chloride. The following conditions gave the best results. Paraformaldehyde (100 mg., containing 3·7 mg. of radioactive formaldehyde), water (0·24 ml.), anhydrous zinc chloride (450 mg.), and benzene (2 ml.) were placed in a test-tube (15 × 2 cm.) and kept at 65°. A rapid stream of dry hydrogen chloride was passed in for 20 min., through a narrow glass tube so that there was efficient mixing. The product was extracted with ether, dried (Na_2SO_4), and distilled, giving fractions (i) bath 110°/20 mm., benzyl chloride (200 mg., 47%), and (ii) bath 170°/20 mm., ωω′-dichloro-*p*-xylene. Much poorer yields were obtained when no water was used in the reaction.

Benzyldimethylamine was prepared by adding benzyl chloride (200 mg.) to a saturated ethanolic solution of dimethylamine (20 ml.). After 24 hr. the solution was refluxed for a few minutes to remove excess of dimethylamine, diluted with water, and extracted with ether. After drying of the extract (Na_2SO_4), benzyldimethylamine was distilled (bath 115°/20 mm.; 150 mg., 70%).

Benzyl-*p*-bromophenacyldimethylammonium bromide (IV) was obtained by mixing *p*-bromophenacyl bromide (400 mg.) and benzyldimethylamine (150 mg.) in dry benzene. After 18 hr. the white precipitate was centrifuged and washed with dry benzene. Recrystallised from ethanol–ether it had m. p. 186—187°, alone or mixed with a non-radioactive specimen. The compounds (IV—VII) are described by Stevens *et al.* (*loc. cit.*).

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THE UNIVERSITY, SHEFFIELD. [*Received, July 12th*, 1955.]

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3 : 5-*Dichloropentan-2-one.*

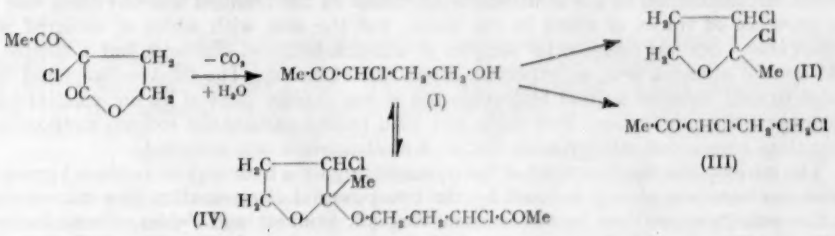
By L. CROMBIE, S. H. HARPER, and B. J. STOKES.

[Reprint Order No. 6638.]

ACCORDING to patent literature (Kerestzy and Wolf, B.P. 609,803, 615,404; Konig, Gerecs, and Foldi, U.S.P. 2,393,109) 2 : 3-dichlorotetrahydro-2-methylfuran (II) may be conveniently prepared from acetylchlorobutyrolactone (Buchman, *J. Amer. Chem. Soc.*, 1936, **58**, 1803) by decarboxylation and treatment with hydrogen chloride. Stevens and Stein (*ibid.*, 1940, **62**, 1045) have shown that the main product from decarboxylation of acetylchlorobutyrolactone is the tetrahydro-2-furyl ether (IV), some 3-chloro-4-oxopentanol, (I) and, perhaps, its cyclic oxide form also being formed. It is presumably this observation which has led Kerestzy and Wolf to formulate their product as (II).

We find that the product from the above reaction, whilst having a reasonable analysis for the tetrahydrofuran (II) differs widely in physical constants from those reported by Paul and Tchelitcheff (*Bull. Soc. chim.*, 1950, **17**, 520) for 2 : 3-dichlorotetrahydro-2-methylfuran prepared by addition of chlorine to 4 : 5-dihydro-2-methylfuran. Furthermore, its infrared spectrum shows a strong band at 1725 cm.$^{-1}$ consistent with an α-chloroketone structure, together with a weaker one at 1773 cm.$^{-1}$ which may be due to lactone

contaminant. It gives a 2 : 4-dinitrophenylhydrazone. A positive iodoform test and colour reactions also support the methyl ketone structure (III). Authentic 2 : 3-dichlorotetrahydro-2-methylfuran (II) (Paul and Tchelitcheff, *loc. cit.*) reacts readily with alkylmagnesium halides to yield 2 : 2′-dialkyl-3-chlorotetrahydrofuran, whereas Kerestzy and Wolf's material gives only a small yield of impure halogen-containing products.



Reformulation of Kerestzy and Wolf's product as 3 : 5-dichloropentan-2-one (III) is consistent with the patent claim that it yields vitamin B_1 when treated with 4-amino-2-methyl-5-thioformamidomethylpyrimidine.

Experimental.—**3 : 5-*Dichloropentan-2-one*.** Sulphuryl chloride (327 g.) was added dropwise to acetylbutyrolactone (308 g.) during 90 min. and the mixture kept for 12 hr. Water (100 ml.) was added and the product isolated with ether. Evaporation gave crude acetylchlorobutyrolactone (376 g.) which was treated with concentrated hydrochloric acid (188 ml.) and heated to 30—50° for 3 hr. with stirring. Hydrogen chloride was passed through the cooled mixture (ice) for 2½ hr. and the product extracted with light petroleum (b. p. 60—80°). The solvent was removed and the residue distilled, three fractions being taken : (1) b. p. 86—88°/15 mm. (101 g.), n_D^{23} 1·4621; (2) b. p. 88—105°/15 mm. (55 g.), n_D^{23} 1·4657; (3) b. p. 105—135°/15 mm. (42 g.), n_D^{23} 1·4800. Refractionation of (1) and (2) gave 3 : 5-*dichloropentan-2-one* (131 g.), b. p. 53°/0·4 mm., 99°/15 mm., n_D^{20} 1·4632 (Found : C, 39·3; H, 4·85; Cl, 45·25. $C_5H_8OCl_2$ requires C, 38·8; H, 5·2; Cl, 45·75%). A yellow **2 : 4-*dinitrophenylhydrazone*** crystallised in plates or needles (from ethanol), m. p. 133—135° (Found : C, 39·75; H, 3·9. $C_{11}H_{12}O_4N_4Cl_2$ requires C, 39·4; H, 3·6%). Recrystallisations from 95% ethanol cause deterioration of the m. p. The ketone gave a violet colour with *m*-dinitrobenzene and sodium hydroxide and a positive Adachi test for a methyl ketone (*Analyt. Chem.*, 1951, **23**, 1491). It reduced Fehling's solution, and gave a silver mirror with ammoniacal silver nitrate. Schiff's test was negative. Paul and Tchelitcheff (*loc. cit.*) give b. p. 56—58°/20 mm., n_D^{20} 1·4804, for 2 : 3-dichlorotetrahydro-2-methylfuran. 1 : 4-Dichloropentan-3-one (Catch, Elliot, Hey, and Jones, *J.*, 1948, 278) has b. p. 64—65°/1·5 mm., n_D^{20} 1·4631.

When 3 : 5-dichloropentan-2-one was treated with methylmagnesium bromide and worked up in the usual way, a small yield of distillable material was formed. This was fractionated at 15 mm., five cuts being taken between 80° and 125°. Refractive indices ranged from n_D^{20} 1·4519 to 1·4758 and chlorine contents from 17·9 to 35·7%, but no homogeneous material was isolated.

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Reaction of 1-(*Nitrophenyl*)*pyrazoles with Alkali.*

By H. P. CROCKER and R. H. HALL.

[Reprint Order No. 6593.]

ATTEMPTED purification of a sample of 1-(2 : 4-dinitrophenyl)pyrazole by percolation of its benzene solution through a column of activated alumina gave a large zone of strongly adsorbed, bright yellow material, which could not be eluted with benzene. Similar results were obtained with a pure specimen; in this case, subsequent elution of the column with

methanol rapidly removed a colourless basic substance and then, more slowly, the yellow material. The base was proved to be pyrazole by direct comparison with an authentic specimen and the yellow substance was identified as sodium 2 : 4-dinitrophenoxide by elementary analysis, comparison with an authentic specimen, and conversion into 2 : 4-dinitrophenol and 2-bromo-4 : 6-dinitrophenol.

The decomposition of the dinitrophenylpyrazole on the alumina was obviously due to the presence of traces of alkali in the latter, but the ease with which it occurred was remarkable. Several commercial samples of alumina behaved similarly, but a sample of acid-treated alumina was, as expected, much less effective. The dinitro-compound was stable to cold aqueous sodium hydroxide but it was rapidly cleaved by hot concentrated aqueous-methanolic sodium hydroxide and with boiling methanolic sodium methoxide a very clean conversion into pyrazole and 2 : 4-dinitroanisole was achieved.

The nucleophilic displacement of the pyrazole ring by a hydroxyl or methoxyl group in these reactions was clearly induced by the two powerful electron-attracting nitro-groups in the *ortho-para*-positions in the benzene ring (cf. Bunnett and Zahler, *Chem. Reviews*, 1951, **49**, 273; Ingold, " Structure and Mechanism in Organic Chemistry," G. Bell and Sons Ltd., London, 1953, p. 797). The presence of only one such group, as in 1-*p*-nitrophenylpyrazole, provided insufficient activation for reaction to occur under similar conditions, the mononitro-compound being recovered unchanged from passage of its benzene solution through alumina or from a short treatment with boiling methanolic sodium methoxide.

Experimental.—Materials. 1-(2 : 4-Dinitrophenyl)pyrazole, pale lemon-coloured prisms, m. p. 109—109·5° (from methanol), and 1-*p*-nitrophenylpyrazole, m. p. 170°, were prepared essentially by Copenhaver's method (U.S.P. 2,515,160, 2,527,533). Finar and Godfrey (*J.*, 1954, 2293) were unable to obtain the dinitro-compound by this method.

Chromatography of 1-(2 : 4-*dinitrophenyl*)*pyrazole.* A solution of pure 1-(2 : 4-dinitrophenyl)-pyrazole (687 mg.) in benzene (70 ml.) was added to a column (60 × 1·5 cm. diameter) of chromatographic alumina (Hopkin and Williams Ltd.), packed in benzene. A large bright yellow zone was obtained. Elution with benzene (500 ml.) gave only a trace (9 mg.) of gum which was not examined further. Elution with methanol (200 ml.) furnished an almost colourless solid (135 mg.) which sublimed at 60—70°/11 mm. to give colourless needles (129 mg., 65%) of pyrazole, m. p. 69—70°, undepressed on admixture with an authentic specimen (Dornow and Peterlein, *Chem. Ber.*, 1949, **82**, 257). Further elution of the column with methanol (800 ml.) afforded sodium 2 : 4-dinitrophenoxide monohydrate (588 mg., 89%), m. p. and mixed m. p. 307° (decomp.). The hydrated sodium salt separated from *n*-butyl alcohol as small yellow needles, m. p. 311—312° (decomp.) (Found : C, 32·7; H, 2·4; N, 12·1; Na, 9·7. Calc. for $C_6H_3O_5N_2Na,H_2O$: C, 32·15; H, 2·25; N, 12·5; Na, 10·25%). Continuous ether-extraction of a mixture of the crude sodium salt (320 mg.) with excess of dilute hydrochloric acid gave 2 : 4-dinitrophenol (256 mg.), m. p. 113°, which crystallised from aqueous ethanol as plates, m. p. and mixed m. p. 114°. The dinitrophenol was characterised as 2-bromo-4 : 6-dinitrophenol, m. p. and mixed m. p. 117°.

Two other commercial samples of activated alumina (Savory and Moore Ltd., " for chromatographic analysis," Grade II, and Peter Spence, Type A) gave similar results. A sample of Peter Spence, Type A, alumina which had been steeped in dilute sulphuric acid at pH 4 for several minutes, then washed with water and dried, was much less effective.

Treatment of 1-(2 : 4-*dinitrophenyl*)*pyrazole with sodium hydroxide.* A mixture of the dinitrophenylpyrazole (500 mg.), methanol (10 ml.), and aqueous sodium hydroxide (5 ml., 40% w/v) was refluxed for 10 min. under nitrogen. The dark-brown solution was diluted with water (50 ml.) and extracted continuously with ether. The extract was concentrated and the small amount of aqueous-methanolic solution which remained was dehydrated azeotropically with methylene dichloride to give, after removal of solvent, a mixture of a yellow solid and colourless crystals. This was triturated with ether (2 × 50 ml.) and filtered, leaving a yellow solid as residue.

The filtrate was concentrated to give a slightly oily, yellowish-brown solid (130 mg.), a portion of which on sublimation at 60°/12 mm. furnished colourless crystals of pyrazole, m. p. and mixed m. p. 68—69°. A second portion (58 mg.) gave a picrate (150 mg.), m. p. 159—161°, raised to 160—161° on recrystallisation from benzene. Admixture with authentic pyrazole picrate (m. p. 162—163°) gave a mixed m. p. of 161—162°.

The yellow solid insoluble in ether was dissolved in methanol, the solution filtered, and the solvent removed to give sodium 2 : 4-dinitrophenoxide (334 mg.), from a portion (169 mg.) of which 2 : 4-dinitrophenol (122 mg.), m. p. and mixed m. p. 113—114°, was prepared by acidification of a concentrated aqueous solution. A further quantity (35 mg.) of dinitrophenol (slightly impure), m. p. 111° (mixed m. p. 112—113°), was obtained from the aqueous solution remaining after the continuous ether-extraction above by acidification followed by continuous ether-extraction.

Treatment of 1-(2 : 4-*dinitrophenyl*)*pyrazole with sodium methoxide.* A mixture of the dinitro-compound (3·59 g.), methanol (60 ml.), and methanolic sodium methoxide (35 ml.; 0·606N) was refluxed under nitrogen for 5 min. The resulting dark-brown solution was poured into water (300 ml.) containing a slight excess of hydrochloric acid, and the pale-cream crude 2 : 4-dinitroanisole (2·95 g., 98%) which separated on cooling was collected. The m. p., 88°, was not changed by chromatography on alumina from benzene, followed by elution with carbon tetrachloride–benzene (1 : 1 by vol.) and subsequent recrystallisation from aqueous ethanol, or by admixture with an authentic specimen, m. p. 88° (recorded m. p.s range from 87° to 96°).

The acidic filtrate obtained as above was extracted with ether (3 × 50 ml.), basified with sodium hydroxide solution, and extracted continuously with ether. One-half of the dried (Na_2SO_4) extract was concentrated and the residue sublimed at 60°/12 mm.; it gave colourless crystals of pyrazole, m. p. and mixed m. p. 68—69°. To the other half was added a slight excess of picric acid, and the resulting solution was concentrated to give pyrazole picrate (1·32 g., 58%), m. p. 155—156°. One recrystallisation from ethanol raised the m. p. to 162—163°, undepressed on admixture with an authentic specimen.

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Some Reactions of o-*Nitrobenzenesulphenyl Bromide.*

By A. BURAWOY, P. RAYMAKERS, and C. TURNER.

[Reprint Order No. 6657.]

SULPHENYL halides are known to condense with phenolic substances such as 2-naphthol and with ketones such as acetone and acetophenone, and to add to olefinic double bonds to form sulphides. Most of the investigations have been carried out with the chlorides, the bromides often being assumed to react in a similar manner. Zincke and Röse (*Annalen*, 1914, **406**, 103), however, observed that 3-nitrotoluene-4-sulphenyl bromide, in contrast to its chloride, with acetone gives bromoacetone and 2 : 2′-dinitro-4 : 4′-ditolyl disulphide, and Kharasch and Bruice (*J. Amer. Chem. Soc.*, 1951, **73**, 3240) noted that fluorenone-1-sulphenyl bromide, unlike its chloride, is converted into the disulphide when heated with acetone, no reference to the fate of the bromine being made.

In the course of other work, we have found that *o*-nitrobenzenesulphenyl bromide reacts with 2-naphthol, acetophenone, or cholesteryl acetate in cold dry ether to yield the disulphide in addition to 1-bromo-2-naphthol, phenacyl bromide, and 5 : 6-dibromocholestanyl acetate respectively, whereas with *cyclo*hexene it behaves like the chloride (Kharasch, Wehrmeister, and Tigermann, *ibid.*, 1947, **69**, 1612), the addition product 2-bromo*cyclo*hexyl *o*-nitrophenyl sulphide being formed. An addition product with 1 : 4-dihydronaphthalene has been recently described by Kharasch, Buess, and Strachan (*ibid.*, 1952, **74**, 3422).

Bromination is probably initiated by slow dissociation of *o*-nitrobenzenesulphenyl bromide into the disulphide and bromine, the latter subsequently reacting in the normal way. This would be similar to the observation that the formation of thiocyanogen and the disulphide occasionally replaces the addition of a sulphenyl thiocyanate to an olefin (Kharasch, Wehrmeister, and Tigermann, *loc. cit.*).

The formation of new addition products of *p*-nitrobenzenesulphenyl chloride and of anthraquinone-1-sulphenyl bromide with *cyclo*hexene is also reported.

Experimental.—Action of o-nitrobenzenesulphenyl bromide on 2-naphthol. A solution of 2-naphthol (1·3 g.) and the sulphenyl bromide (4·7 g.) in dry ether (50 c.c.) was kept for 10 days at room temperature. Hydrogen bromide was evolved and almost pure 2 : 2′-dinitrodiphenyl disulphide separated [2·75 g.; m. p. and mixed m. p. 195° (from benzene)]. Steam-distillation of the mother-liquor yielded 1-bromo-2-naphthol [1·4 g., 70%; m. p. and mixed m. p. 83—84°, (from light petroleum)].

Action of o-nitrobenzenesulphenyl bromide on acetophenone. A solution of acetophenone (1·2 g.) and the sulphenyl bromide (4·7 g.) in dry ether (50 c.c.) was kept for 6 days at room temperature. Hydrogen bromide was evolved and almost pure 2 : 2′-dinitrodiphenyl disulphide separated [2·75 g.; m. p. 195° (from benzene)]. Steam-distillation of the mother-liquor yielded phenacyl bromide [1·0 g., 52%; m. p. and mixed m. p. 50° (from aqueous ethanol)].

Action of o-nitrobenzenesulphenyl bromide on cholesteryl acetate. A solution of cholesteryl acetate (4·3 g.) and the sulphenyl bromide (4·7 g.) in ether (50 c.c.) was kept for 30 days. 2 : 2′-Dinitrodiphenyl disulphide crystallised out [2·6 g.; m. p. 195° (from benzene)]. After removal of ether from the mother-liquor under reduced pressure, the residue crystallised from ethanol to give needles of 5 : 6-dibromocholestanyl acetate [1·6 g., 27%; m. p. 115—116°, not depressed by a specimen prepared by the action of bromine in carbon tetrachloride on cholesteryl acetate (Wislicenus and Moldenhauer, *Annalen*, **1868**, **146**, 178)].

Action of o-nitrobenzenesulphenyl bromide on cyclo*hexene.* A solution of the sulphenyl bromide (5 g.) and *cyclo*hexene (5 g.) in dry ether (50 c.c.) was kept for 24 hr. *2-Bromocyclohexyl o-nitrophenyl sulphide* separated (5·3 g., 79%). Crystallisation from ethanol gave large yellow prisms, m. p. 96·5—97·5° (Found: C, 45·7; H, 4·5. $C_{12}H_{14}O_2NSBr$ requires C, 45·6; H, 4·4%). No hydrogen bromide could be detected. A similar result was obtained in a reaction in boiling carbon tetrachloride.

Action of p-nitrobenzenesulphenyl chloride on cyclo*hexene.* A solution of the sulphenyl chloride (3·8 g.) and *cyclo*hexene (5 g.) in dry ether (50 c.c.) was kept for 3 days at room temperature. Ether and excess of *cyclo*hexene were removed under reduced pressure and the crystalline residue of *2-chlorocyclohexyl p-nitrophenyl sulphide* was washed with light petroleum and collected (4·6 g., 85%). Crystallisation from light petroleum (b. p. 40—60°) gave yellow prisms, m. p. 66—67° (Found: C, 53·4; H, 5·1. $C_{12}H_{14}O_2NSCl$ requires C, 53·0; H, 5·2%). No hydrogen bromide could be detected. A similar result was obtained in a reaction in boiling carbon tetrachloride.

Action of anthraquinone-1-sulphenyl bromide on cyclo*hexene.* The sulphenyl bromide (2·7 g.), *cyclo*hexene (2·1 g.), and dry carbon tetrachloride (50 c.c.) were refluxed for 30 hr. After removal of the solvent *1-anthraquinonyl 2-bromocyclohexyl sulphide* was collected almost quantitatively (3·2 g.). Crystallisation from acetic acid gave light brown needles, m. p. 169—170° (Found: C, 59·6; H, 4·4. $C_{20}H_{17}O_3SBr$ requires C, 59·8; H, 4·2%).

College of Technology, University of Manchester. [*Received, July 28th*, 1955.]

OBITUARY NOTICE.

JOHN THEODORE HEWITT.

1868—1954

At the age of nearly 86, and close to his cottage home in the country, John Theodore Hewitt was knocked down and killed by a motor-car which was in charge of an admittedly irresponsible driver. This was indeed a tragedy, for Hewitt had not yet grown old and was as keenly interested in the Chemistry of 1954 as he had been in that of 1894. Some of us who had had the good fortune to be his students had been planning for him to tell us, in writing or in a lecture, what he thought of the last 50 years, with its curious mixture of change and progress. We shall never know now, but we can be sure that he would have found it in his heart to tell us that all was well with chemistry: for had he not seen personality after personality dominate the chemical stage, one and all to be replaced by new figures, with new themes, new phrases, new dogmas and, in a few instances, new outlooks? Neither he nor any of his students ever became members of the power groups in chemistry and for this reason, if for no other, Hewitt stands almost alone as a person and . . . I was about to say " as a teacher ": this however would be wrong, for he was better than a teacher: he provided the atmosphere in which his students were unable to resist the desire to learn.

Hewitt was born at Windsor on October 12th, 1868. His father, who had a coachbuilding business, died at the age of 34. Hewitt's mother was able to buy a small private school in Newbury. Some years later Mrs. Hewitt secured the post of Headmistress at the Girls' College and High School of Southampton, so that she and John Theodore and his sister Marian went to this city to live. Mrs. Hewitt was able to induce the Principal of The Hartley Institute (now The University of Southampton) to allow her son to attend classes in chemistry, mathematics, machine drawing, and classics. The instruction in chemistry was given by the Southampton Public Analyst, James Brierley. Hewitt and W. R. Bower (later a physicist) won National Scholarships at the Normal School of Science (afterwards the Royal College of Science—Imperial College of Science and Technology). Hewitt, who was not 16 years of age until October 12th, 1884, worked in Percy F. Frankland's laboratory, mainly on qualitative inorganic analysis, and, from October 1885 to February 1886, studied physics and then, until the summer, also geology. During this period he decided that chemistry was more in his line than engineering, and in October 1886 he attended T. E. Thorpe's inorganic lectures. Later in the year he experienced the greatest pleasure in listening to Japp on organic chemistry. By now Hewitt was living with his mother and sister near St. Denys Station in Southampton. He seems from an early age to have been fascinated by railways. More than once he travelled on the footplate of fast trains on the Southampton run, and later in life he was full of reminiscences of incidents of railway journeys. It is curious to reflect that in his young manhood the railway locomotive held the record for speed.

In December 1886 Hewitt obtained a foundation scholarship at St. John's College, Cambridge. In June 1887 he became an Associate of the Royal College of Science (as it was later), but hoped that he could then escape from an academic life. In this he was unsuccessful, and he started at Cambridge in the autumn. He attended lectures given by James Dewar, Pattison Muir, and J. J. Thomson, and passed Part I of the Natural Sciences Tripos and the London Intermediate in the summer of 1889. Among his friends at Cambridge were R. A. Lehfeldt, Alfred Mond, F. F. Blackman, and F. S. Locke. His main recreations were walking and poker. His Part II chemistry was done under S. Ruhemann, W. J. Sell, and H. J. H. Fenton. Hewitt found Ruhemann an inspiring teacher. When, in 1890, he had taken a First in Part II, he started an investigation on " chlorinated phenylhydrazines " at Ruhemann's suggestion and did some demonstrating. In October 1890 he obtained a First in the London degree and in the following spring went to Heidelberg. Here he worked with L. Gattermann on the action of ammonia on quinalizarin.

The " academic freedom " of those days is well illustrated by the fact that in October 1891 Hewitt worked in Cambridge on phenylhydrazines and on citraconfluorescein (the condensation product of citraconic anhydride and resorcinol) and at the end of the May term went to Berlin, continuing his citraconfluorescein research in Tiemann's laboratory. Then, after spending the Michaelmas term demonstrating and doing research in Cambridge, he put in a few weeks in

Heidelberg and took his Ph.D. there in January 1893. The same work, with a little added to it, enabled him to obtain the London D.Sc. in June 1893. He spent the summer working at the Hartley Institute in Southampton and there discovered the first arylazophenol hemihydrates.

At the end of the Lent Term 1894, when he was only 25 years of age, Hewitt applied for and obtained a post as " Professor " of Chemistry at the People's Palace Technical Schools. His teaching duties included twelve hours a week in the Day School and twelve hours a week in the evening classes. J. L. S. Hatton, the mathematician, was the Director of Studies of the evening students and he and Hewitt were an enthusiastic pair. It would be wrong to omit to mention David Allan Low, the engineer, who was Headmaster of the Day School. These three men were largely responsible for the initial development of this centre of learning and research, which later became East London College, a School of the University. Of the three, Hewitt was the active investigator. He soon built up a keen research group which included F. G. Pope (the demonstrator), H. A. Phillips, A. E. Pitt, J. J. Fox, and T. S. Moore. In 1903 Hewitt and Pope were joined by Clarence Smith. Together these three taught and inspired many generations of students, though always Hewitt was the king-pin. He was elected a Fellow of the Royal Society in 1910 and shortly afterwards became a Professor in the University. In 1934, when the College changed its name, Hewitt was made one of the first Fellows of Queen Mary College.

Hewitt had a magnetic personality. When he bustled into the lecture room the pace was set for an hour's concentrated and interesting study of whatever was afoot. Hewitt brought out the best in his students by the example he set : a vigorous man to whom anything chemical was worth while. Considering the size of the chemistry department at East London College in his time, it is extraordinary how many of his students had distinguished academic or industrial or Governmental careers. The writer recalls the following names : S. J. M. Auld, G. M. Bennett, R. K. Cannan, J. C. Drummond, S. Glasstone, J. J. Fox, W. G. Hiscock, J. Kenner, R. W. Merriman, A. D. Mitchell, T. S. Moore, H. A. Phillips, A. E. Pitt, F. B. Thole, and T. F. Winmill, but there may be many more.

In addition to his academic investigations, Hewitt was interested in a number of commercial things. In 1900 or thereabouts he proposed a process for maturing whisky quickly, by treating the raw spirit with the calcium salt of phenylhydrazine-*p*-sulphonic acid, which should remove any furfuraldehyde. A well-known Scotch whisky firm refused the idea since they thought it led to the loss of desirable as well as of undesirable components, but an Irish distillery worked the Hewitt process for some years. The reputation Hewitt had gained as an expert on wines and spirits led to his being consulted by the French wine industry. Hewitt also acquired considerable prestige as a result of acting as an expert witness in the famous Bayer " aspirin " case.

Having been in touch with Germany for a long period, Hewitt was not surprised by the events of 1914. He began some investigations of commercially useful methods of making acetic anhydride and suggested the application of the Jacobsen reaction for the conversion of benzene–xylene mixtures into toluene. In 1915 he was commissioned in the army as " Major, General List, attached Royal Engineers." He and H. R. Le Sueur were sent to the Dardanelles. Here Hewitt seems to have spent his time receiving rather ambiguous instructions : he did water analyses and gave advice about a cargo of chlorine cylinders. He returned to England in January 1916 and was " seconded " to the Ministry of Munitions. In due course he was given the direction of an ex-German laboratory at Chiswick (as he said, suspiciously near certain reservoirs). Here he was assisted by Clarence Smith, W. J. Jones, H. S. Patterson, and W. S. Denham. This group worked on picric acid and later on arsenicals. The post suited Hewitt perfectly, as he had to travel about a good deal and was always in contact with the industrial side of things.

A few months after the Armistice, Hewitt, who had resigned from his professorship and been made an O.B.E., joined with T. D. Morson, C. S. Roy, Clarence Smith, Julian Baker, and Miss Hewitt to form a company to make fine chemicals, the site for operations being Hewitt's latest home (he moved rather frequently), Sutton Manor House, Heston, Middlesex. The company made ethyl chloroformate, quinine ethyl carbonate, quinolines, phenylhydrazine, and other products, but in 1924 became almost obsolescent. Hewitt and his sister moved to a very countrified address in 1928 : Rose Cottage, Hurst, near Twyford. Gas, electricity, water, and main drainage were all lacking, but at the age of 60 Hewitt thought this property to be what he fancied. He built a couple of sheds and so had a laboratory, a library, and a balance room. He did some consulting work and some examining, attended meetings of the Chemical Society and of the Board of Studies in Chemistry in London, and could often be found in the Chemical

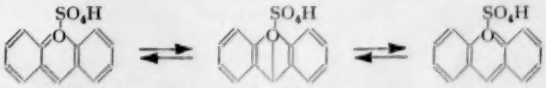
Society library reading the journals. He was acutely interested in, but had qualms about, the quantum mechanical treatment of chemical problems.

In 1943 his sister died, but Hewitt went on living in Rose Cottage with three cats, and still made his periodic visits to town, as debonair as ever.

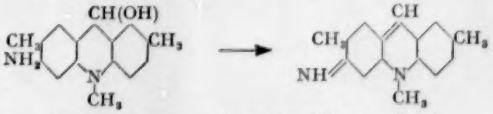
Hewitt's earliest original work was on the "hemihydrates" and the "hydrochlorides" of certain hydroxyazo-compounds and on citraconfluorescein. The constitution of the hydroxyazo-compounds was the subject of controversy for about a quarter of a century. There seemed to be some evidence that *o*-hydroxyazo-compounds were quinonehydrazones whereas the isomeric *p*-compounds had true hydroxyazo-structures. Hewitt and his school at East London College attacked this problem in a number of ingenious ways, at first by studying bromination and nitration and later by determining ultraviolet absorption spectra. One of the most important outcomes of these investigations was the development of the idea that depth of colour was related to the length of the conjugated system in the molecule. Closely allied to this was Hewitt's work on fluorescence, which he thought was due to "double symmetrical tautomerism," that is, the oscillation of the bonds between two equivalent structures.

His picture of anthracene :

is no mean fore-runner of the theory of "resonance," and he applied similar arguments to explain, for example, the fluorescence of solutions of xanthhydrol in concentrated sulphuric acid :

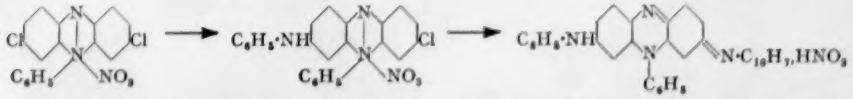


Any coloured substance, and particularly anything that could be used as an "indicator," attracted Hewitt's interest. He published a number of important papers on the relation between carbinol bases and anhydro-bases in the acridine series :



(the benzene rings are as Hewitt wrote them)

The safranines also occupied Hewitt's attention over a number of years : for example, he showed that dichlorophenylphenazonium nitrate reacted with aniline in the cold to give a product which reacted in the hot with α-naphthylamine to give an anilino-naphthylamino-compound :



Hewitt made important contributions to our knowledge of the association of phenols, of the substitution reactions of phenols, and of the constitution of nitrophenols. It is not without interest to note that Moore and Winmill, sometimes credited with the conception of the hydrogen bond, were both Hewitt's students : and no theory could have had a better god-parent.

With Buttle in 1909 Hewitt concluded, from ultraviolet absorption spectra studies, that of the two possible quinonoid forms of the metallic salts of 2 : 4-dinitrophenol the *para* was preferred :

Previously, with Kenner and Silk, Hewitt had observed that whereas three molecular proportions of bromine converted phenol into tribromophenol, one or two molecules of bromine

gave mixtures of phenol with mono-, di-, and tri-bromophenol. It was deduced that the mineral acid produced in the bromination slowed down further substitution and a brilliant conclusion was come to that bromination in presence of sulphuric acid might tend to stop at the dibromo-stage. This was confirmed experimentally. However, even in those days, when there was no authoritarian doctrine about chemical reactions, it was found impossible to apply the ideas to the naphthalene series : α-naphthol with one molecule of bromine gave a mixture of unchanged naphthol with 2 : 4-dibromo-α-naphthol.

Winmill's collaboration with Hewitt resulted in several interesting publications. They showed that the arsenic di-iodide described in the literature was As_2I_4 and not AsI_2 as previously thought, but that it was useless as a source of cacodyls. They also devised an ingenious apparatus for the determination of the surface tension of a compound under its own vapour. They noticed that *ortho*-substituents exerted a steric effect on the association of phenols.

Hewitt's versatility is shown by the fact that apart from the subjects already mentioned, he published papers on natural gas, the Zeisel determination of methoxyl, the synthesis of quinolines, and the by-products of alcoholic fermentation. At the age of 77 he patented a modification of the Skraup quinoline synthesis. Unlike some patents this one works !

There can be no doubt that although Hewitt got a lot out of life he gave to it more. He was an individualist whom even to imitate was to achieve something well above the ordinary. To anyone who has the time (and the knowledge) to reflect, the period during which Hewitt lived was more crammed with chemical adventure than any similar period since time began.

E. E. Turner.

THE INDEX

TO THIS VOLUME HAS BEEN REMOVED

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THE BEGINNING OF THE FILM FOR THE

CONVENIENCE OF READERS.

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E. E. Turner.

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M. Peligot has communicated to the Annales de Chimie et Physique (xvii, 368) a short note on the preparation of uranium. A mixture of 75 grammes of uranous chloride, 150 grammes of dry potassium chloride, and 50 grammes of sodium in fragments is introduced into a porcelain crucible, itself surrounded by a plumbago crucible. The reaction is effected in a wind furnace at the temperature of redness; but the heat must be increased for a short time at the close of the operation. In the black slag may be found, after cooling, globules of fused uranium.

M. Peligot finds uranium

The new method of producing uranium was announced in the first issue of Nature in 1869. Monsieur Peligot, who twenty-eight years before had first isolated the metal, discovered by Klaproth in 1789, was opening the door a little more widely to the possibility of an Atomic Age a century later. In recent years the priority attaching to the atomic energy programme has restricted their availability, but uranium compounds are now again available and figure among the several thousand fine chemicals of very high purity supplied by B.D.H. for science and industry. The B.D.H. catalogue contains more than 6,000 laboratory chemicals and reagents. Of these some hundreds in addition to 'AnalaR' and 'M.A.R.' chemicals, are labelled with specifications of purity.

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PROCEEDINGS

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SCIENTIFIC MEETINGS DURING MARCH, 1955

LONDON.

Thursday, March 17th, 1955, at 7.30 p.m.

Pedler Lecture, **Some Problems in the Chemistry of the Hemicelluloses,** by Professor E. L. Hirst, M.A., D.Sc., LL.D., F.R.S. To be given in the Rooms of the Society, Burlington House, W.1.

ABERDEEN.

Thursday, March 17th, 1955, at 7.30 p.m.

Lecture, **Fluorescence of Solutions,** by Dr. E. J. Bowen, M.A., F.R.S. Joint meeting with the Royal Institute of Chemistry and the Society of Chemical Industry. To be held at Robert Gordon's Technical College.

BIRMINGHAM.

Friday, March 4th, 1955, at 4.30 p.m.

Lecture, **Ionisation in Organic Chemistry,** by Professor E. D. Hughes, D.Sc., F.R.I.C., F.R.S. Joint meeting with Birmingham University Chemical Society. To be held in the Chemistry Department, The University.

BRISTOL.

Thursday, March 3rd, 1955, at 7.0 p.m.

Lecture, **The Fuel Scientist: Training and Using Britain's Greatest Asset,** by Professor A. L. Roberts, Ph.D., F.R.I.C. Joint meeting with the Royal Institute of Chemistry, the Society of Chemical Industry, and the Institute of Fuel. To be held in the Chemistry Department, The University.

Thursday, March 17th, 1955, at 7.0 p.m.

Lecture, **Recent Advances in Photography,** by Dr. H. Baines, F.R.I.C. Joint meeting with the Royal Institute of Chemistry and the Society of Chemical Industry. To be held in the Chemistry Department, The University.

EDINBURGH.

Thursday, March 10th, 1955, at 7.30 p.m.

Lecture, **The Changing Face of the Gas Industry,** by Dr. A. Marsden, M.B.E., F.R.I.C. Joint meeting with the Royal Institute of Chemistry and the Society of Chemical Industry. To be held at the North British Station Hotel.

GLASGOW.

Friday, March **18***th*, **1955**, *at* **7.15** *p.m.*

Lecture, **The Shapes of Molecules,** by Dr. J. W. Linnett, M.A. To be given at the University.

HULL.

Thursday, March **3***rd*, **1955**, *at* **6.0** *p.m.*

Lecture, **Some Recent Progress in Natural Product Chemistry,** by Professor D. H. R. Barton, D.Sc., F.R.I.C., F.R.S. To be given at the University.

IRISH REPUBLIC.

Friday, March **4***th*, **1955**, *at* **7.45** *p.m.*

Lecture, **Organic Inclusion Compounds,** by Professor W. Baker, M.A., D.Sc., F.R.I.C., F.R.S. Joint meeting with the Werner Society to be held in the Chemistry Department, Trinity College, Dublin.

Wednesday, March **23***rd*, **1955**, *at* **7.45** *p.m.*

Lecture, **Recent Advances in Acetylene Chemistry,** by Professor R. A. Raphael, Ph.D., A.R.I.C. To be given in the Chemistry Department, University College. Dublin.

LEEDS.

Thursday, March **10***th*, **1955**, *at* **6.30** *p.m.*

Lecture by Sir Alexander Todd, M.A., D.Sc., F.R.I.C., F.R.S. Joint meeting with the Leeds University Chemical Society. To be held in the Chemistry Lecture Theatre, The University.

Monday, March **14***th*, **1955**, *at* **6.30** *p.m.*

Royal Institute of Chemistry Lecture, **The Biochemistry of the Marine Algæ,** by Dr. F. N. Woodward, B.Sc., F.R.I.C. To be given in the Chemistry Lecture Theatre, The University. (All Fellows are invited.)

LIVERPOOL.

Thursday, March **3***rd*, **1955**, *at* **5.0** *p.m.*

Lecture, **The Mode of Action of Pyridoxine,** by Dr. H. M. Sinclair, B.Sc., M.A. Joint meeting with the University Chemical Society, the Royal Institute of Chemistry, the Society of Chemical Industry, and the British Association of Chemists. To be held in the Chemistry Lecture Theatre, The University.

MANCHESTER.

Thursday, March **10***th*, **1955**, *at* **5.0** *p.m.*

Meeting for the Reading of Original Papers. To be held in Room E.17, College of Technology, Manchester.

NEWCASTLE AND DURHAM.

Friday, March **11***th*, **1955**, *at* **5.30** *p.m.*

Bedson Club Lecture, **The Rapid Reaction of Hæmoglobin with Oxygen and Carbon Monoxide,** by Professor F. J. W. Roughton, F.R.S. To be given in the Chemistry Building, King's College, Newcastle-on-Tyne. (All Fellows are invited.)

Monday, March 14*th*, 1955, *at* 5.15 *p.m.*

Lecture, **New Developments in Analytical Chemistry,** by Dr. R. Belcher. Joint meeting with Durham Colleges Chemical Society. To be held in the Science Laboratories, The University, Durham.

NORTHERN IRELAND.

Thursday, March 10*th*, 1955, *at* 7.15 *p.m.*

Lecture, **The Influence of Structure on some Properties of Polymers,** by Dr. R. J. W. Reynolds, B.Sc., A.R.I.C. Joint meeting with the Society of Chemical Industry. To be held in the Agriculture Lecture Theatre, Queen's University, Belfast.

SHEFFIELD.

Thursday, March 3rd, 1955, *at* 7.30 *p.m.*

Lecture, **Structures and Properties of Clathrate Compounds,** by Mr. H. M. Powell, M.A., F.R.S. Joint meeting with Sheffield University Chemical Society. To be held in the Chemistry Lecture Theatre, The University.

SOUTHAMPTON.

Friday, March 11*th*, 1955, *at* 5.0 *p.m.*

Lecture, **Reactions in Liquid Dinitrogen Tetroxide,** by Dr. C. C. Addison, F.R.I.C. Joint meeting with Southampton University Chemical Society. To be held in the Chemistry Department, The University.

SOUTH WALES.

Friday, March 11*th*, 1955, *at* 6.0 *p.m.*

Lecture, **Chemistry of Colchicine,** by Dr. J. W. Cook, D.Sc., F.R.S. Joint meeting with the Royal Institute of Chemistry and the University College of Swansea Chemical Society. To be held in the Chemistry Department, University College of Swansea.

OFFICIAL ANNOUNCEMENTS

DEATHS

The Council regrets to announce the deaths of the following Fellows :

	Elected.	Died.
Geoffrey Broughton (Rochester, N.Y.)	Feb. 16th, 1933.	Sept. 10th, 1954.
Harold Heron (London, S.E.24)	June 20th, 1912.	Dec. 4th, 1954.
Francis Desmond Hills (London, S.E.23)	Sept. 15th, 1943.	Nov. 14th, 1954.
Reginald Oscar Culmer Hurst (Thundersley)	Feb. 16th, 1911.	Dec. 14th, 1954.
James Roberts (Glasgow, W.2)	Feb. 16th, 1899.	Dec. 31st, 1953.
William Scholes (Manchester)	April 30th, 1902.	Nov. 20th, 1954.

CONGRATULATIONS.

The President has conveyed the congratulations of the Society to the following Fellows who completed 60 years of Fellowship on December 6th, 1954 :

Frederick John Allen (Southwold).
David Runciman Boyd (Fordingbridge).
George Cecil Jones (Hastings).
William Henry Lewis (Dawlish).

and to the following who completed 50 years of Fellowship on December 1st, 1954 :

James Edward Cunningham (Bodiosa-Viseu, Portugal).
Thomas Campbell James (Aberystwyth).

ACKNOWLEDGMENTS.

Acknowledgment is made of gifts of the Society's publications from Mr. H. H. Hughes and Mr. W. B. Saville.

ELECTION OF NEW FELLOWS.

The following 67 candidates were elected Fellows of the Society on December 16th, 1954 :

Edward William Abel.
Patricia Anderson.
John Richard Armstrong.
Philip George Ashmore.
Clinton E. Ballou.
Robert Kenneth Bartlett.
Franklin Anthony Billig.
David Booth.
John Kenneth Bradley.
Dennis Godfrey Brooke.
David Michael Butcher.
Neil Mitchell Churchman.
Raymond O. Clinton.
Kenneth William Daisley.
Daniel Salman Daniel.
Patrick Francis Devitt.
George Henry Dorion.
John Phillip Elder.
A. Foley.
Alfred H. Frye.
William Charles Greenstreet.
Norman Hulton Haddock.
Desmond Hall.
Peter Hay.
Andrew William Henderson.
Russell John Hill.
Alan Holroyd.
Mikio Hori.
Robert Frank Hutton.
David Griffith Jenkin.
Edward Tudor Lloyd.
Andrew John Manson.
Raymond Joseph Marklow.
Philip Arthur Mayor.
George Francis John Moir.
Duane Francis Morrow.
John David Newson.
Gordon Ramsay Nicholson.
Paul Adrian Lanyon Northcott.
Hubert Charles Oldland.
Milton Orchin.
Leonello Paoloni.
Rupert Beresford Pearson.
Geoffrey Frederick Phillips.
Raghunath Prasad Rastogi.
Joseph F. Reuwer.
George Riga de Spinoza.
John Shipley Rowlinson.
Takeo Sakan.
Warwick Slough.
David Bryan Sowerby.
Roy Stenson.
William Templeton.
Kumarbhai Ambalal Thaker.
Jean K. Thompson.
Martin Leslie Elliot Tobe.

Ronald Jefferson Townsend.
Peter Stanley Uzzell.
Cyril John Vesey.
Arthur James Vize.
Kenneth Wade.
Antony John West.
Noel David Weston.
Donald Brian Whitehouse.
Donald Graham Wilkinson.
David John Williams.
William Sydney Wise.

RESEARCH FUND.

The Council has approved the following grants from the Research Fund :

	£	s.	d.
Akisanya, A. (Ibadan)	12	0	0
Bacon, R. G. R. (Belfast)	30	0	0
Battersby, A. R. (Bristol)	20	0	0
Bevan, C. W. L. (Ibadan)	20	0	0
Brown, M. G. (Winchester)	12	0	0
Brown, R. D. (Melbourne)	40	0	0
Caldin, E. F. (Leeds)	20	0	0
Campbell, I. G. M. (Southampton)	30	0	0
Catchpole, A. G. (Derby)	50	0	0
Coates, G. E. (Durham)	30	0	0
England, B. D. (Ibadan)	13	0	0
Evans, A. G. (Cardiff)	60	0	0
Everest, D. A. (London)	20	0	0
Feakins, D. (London)	10	0	0
Foley, A. (Ibadan)	10	10	0
Greenwood, N. N. (Nottingham)	30	0	0
Hirst, J. (Ibadan)	10	0	0
Hussain, F. (London)	15	0	0
Hutchison, H. P. (Dublin)	30	0	0
Le Fèvre, R. J. W. (Sydney)	40	0	0
Lyons, L. E. (Sydney)	40	0	0
Nicholson, D. C. (London)	10	0	0
Ollis, W. D. (Bristol)	20	0	0
Parker, R. E. (Southampton)	25	0	0
Perry, G. S. (Ontario)	24	0	0
Pink, R. C. (Belfast)	20	0	0
Ramage, G. R. (Huddersfield)	10	0	0
Raphael, R. A. (Belfast)	26	0	0
Rees, A. H. (Ibadan)	12	0	0
Rothstein, E. (Leeds)	20	0	0
Taylor, J. L. (London)	15	0	0
Williams, R. J. (Leeds)	20	0	0

AMERICAN CHEMICAL SOCIETY PUBLICATIONS 1955.

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MINUTES OF SCIENTIFIC MEETINGS

Minutes of a

SCIENTIFIC MEETING

held at Burlington House on Thursday, December 2nd, 1954, at 7.30 p.m.

The President, PROFESSOR W. WARDLAW, C.B.E., D.Sc., F.R.I.C., was in the Chair and welcomed to the meeting Professor M. M. Dubinin, Secretary of the Academy of Sciences, U.S.S.R.

MINUTES.

The Minutes of the Scientific Meeting held in the Large Chemistry Lecture Theatre of the Imperial College of Science and Technology on November 18th, 1954, were read, and were confirmed and signed.

FORMAL ADMISSION OF FELLOWS.

The following were admitted Fellows of the Society : Pauline Vicary, D. E. C. Corbridge, J. C. McCoubrey.

SCIENTIFIC COMMUNICATIONS.

The following papers were read and discussed :

" The Structure of Infusible White Precipitate from Nuclear Resonance Spectra." By C. M. Deeley and R. E. Richards.

" Five-covalent Tripyridyl Complexes of Bivalent Metals." By D. E. C. Corbridge and E. G. Cox.

" Vibrational Spectra and Structures of Some Acid Hydrates." By D. J. Millen and E. G. Vaal.

Minutes of a

SCIENTIFIC MEETING

held at Burlington House, on Thursday, December 16th, 1954, at 7.30 p.m.

The President, PROFESSOR W. WARDLAW, C.B.E., D.Sc., F.R.I.C., was in the Chair.

MINUTES.

The Minutes of the Scientific Meeting held at Burlington House, on December 2nd, 1954, were read and were confirmed and signed.

VACANCIES ON COUNCIL.

The list of vacant places on the Council to be filled at the Annual General Meeting to be held in London on Friday, April 1st, 1955, was read.

FORMAL ADMISSION OF FELLOWS.

Mr. P. R. Hudleston was admitted a Fellow of the Society.

HUGO MÜLLER LECTURE.

The President called upon Professor G. R. Clemo, D.Sc., F.R.S., to deliver the Hugo Müller Lecture entitled " Some Newer Aspects of the Organic Chemistry of Nitrogen." At the conclusion of the Lecture, a vote of thanks to Professor Clemo for his Lecture, proposed by the President, was carried with acclamation.

LIST OF APPLICATIONS FOR FELLOWSHIP

(Fellows wishing to lodge objection to the election of these candidates should communicate with the Honorary Secretaries within ten days of the date of publication of the Journal *for January, 1955. Such objections will be treated as confidential. The forms of application are available in the Library.)*

Aitken, Marjorie Mary. British. 43, Edgbaston Park Road, Birmingham 15. Undergraduate at Oxford University. *Signed by:* L. A. K. Staveley, D. Hodgkin.

Allman, Peter Cyril James, B.Sc. (Lond.). British. Eastlea, Canonsfield Road, Welwyn, Herts. Library Services Manager at Imperial Chemical Industries, Plastics Division. *Signed by:* P. A Small, O. J. Walker.

Anderson, Laurence Edward. British. 57, Greenways, Beckenham, Kent. Undergraduate at Oxford University. *Signed by:* G. T. Young, L. A. K. Staveley.

Asquith, Jack, A.R.I.C. British. 48, Westby Street, Lytham, Lancs. Chemist with U.K. Atomic Energy Authority. *Signed by:* H. K. Pindred, K. Shorrock.

Ayer, Donald, E., B.S. (Yale). American. 2, Strong Place, Boston, Massachusetts, U.S.A. Graduate Student at Massachusetts Institute of Technology. *Signed by:* D. W. H. McDowell, C. G. Swain.

Baker, Alfred Francis Hayes, M.Sc. (New Zealand). British. c/o University College, Ibadan, Nigeria. Lecturer. *Signed by:* C. W. L. Bevan, A. H. Rees.

Bauman, Robert Andrew, Ph.D. (Ill.), B.S. (Rochester). American. 70, South Munn Avenue, East Orange, New Jersey, U.S.A. Research Chemist with Colgate–Palmolive Co., Jersey City. *Signed by:* N. O. V. Sonntag, R. L. Kronenthal.

Benn, Michael Hewitt, B.Sc. (Lond.), A.R.C.S. British. Armstrong Laboratory, Royal College of Science, South Kensington, S.W.7. Postgraduate Research Student. *Signed by:* R. P. Linstead, L. N. Owen.

Bennett, John Ruskin, B.A. (Cantab.). British. 1301, 11 Street E., Saskatoon, Saskatchewan, Canada. Research Student. *Signed by:* R. N. Haszeldine, A. G. Sharpe.

Berger, Arieh, M.Sc. and Ph.D. (Jerusalem). Israeli. Weizmann Institute of Science, Rehovoth, Israel. Research Chemist. *Signed by:* I. Dostrovsky, D. Samuel.

Bieganski, Jan Antoni, B.A. (Oxon.). Polish. 37, Kempsford Gardens, London, S.W.5. Research Student. *Signed by:* L. A. K. Staveley, N. Polgar.

Boake, Edward Edmond, M.A. (Cantab.). British. c/o A. Boake Roberts and Co. Ltd., 100, Carpenters Road, Stratford, London, E.15. Manufacturing Chemist. *Signed by:* M. F. Carroll, B. D. T. Sully.

Boast, Nevison George. British. Letheringsett, Holt, Norfolk. Student at St. Peter's Hall, Oxford. *Signed by:* L. A. K. Staveley, D. A. Long.

Briess, Peter, L.Sc. (Geneva). British. 12, Goodyers Gardens, Hendon, London, N.W.4. Chemist and Manager at B. and P. Laboratories. *Signed by:* S. Pickholz, J. G. Cockburn.

Bull, George Herbert, A.R.I.C. British. 36, Bedford Avenue, Barnet, Herts. Chemist at the Research Laboratories, Elliott Bros. Ltd., Borehamwood. *Signed by:* R. L. Edwards, R. Hemming.

Burkhill, Peter Irlam, B.Sc. (Liv.). British. 58, Victoria Road, Crosby, Liverpool 23. Research Student at Liverpool University. *Signed by:* A. McGookin, W. B. Whalley.

Cardy, Charles Frederick. British. 3, Herd Lane, Corringham, Stanford-le-Hope, Essex. Laboratory Assistant at the London and Thames Haven Oil Wharves, Ltd. *Signed by:* A. J. Page, C. R. Barnes.

Carrington, Thomas Ronald, B.Sc. and Ph.D. (Birm.). British. c/o 58, Headingley Road, Handsworth, Birmingham 21. Research Chemist at Glaxo Laboratories. *Signed by:* E. J. Bourne, S. A. Barker.

Carruthers, John. British. 23, Kelso Street, Glasgow, W.3. Assistant Chemist, S.C.W.S. Ltd., Glasgow, C.3. *Signed by:* R. Stevenson, G. T. Newbold.

Caverhill, Alan Ryton, M.Sc. (New Zealand), Ph.D. (Manc.). British. 37, Cringle Road, Levenshulme, Manchester 19. Chemist at I.C.I. Terylene Council. *Signed by:* A. Marks, M. A. T. Rogers.

Chapman, Dennis, M.Sc. (Lond.), Ph.D. (Liv.). British. 29, Wharfedale Avenue, Prenton, Birkenhead, Cheshire. Research Physicist at Unilever, Ltd., Port Sunlight. *Signed by:* P. N. Williams, G. C. Hampson.

Cohen, Mendel David, M.Sc. (South Africa), Ph.D. (Iowa). British. Department of Optics, Weizmann Institute of Science, Rehovoth, Israel. Research Chemist. *Signed by:* W. J. Rosenfelder, I. Dostrovsky.

Collis, Michael John, B.Sc. (Lond.). British. The Pines, Hadlow, Tonbridge, Kent. Research Student. *Signed by:* D. R. Goddard, A. M. James.

Cooksley, Michael Victor. British. 2, Britannia Cottages, Margate Road, Ramsgate, Kent. Undergraduate at Oxford University. *Signed by:* L. A. K. Staveley, R. E. Richards.

Coope, Peter Jackson, B.Sc. (Lond.). British. 31, Gilda Crescent Road, Eccles, Nr. Manchester. Research Student at Royal Technical College, Salford. *Signed by:* W. P. Thistlethwaite, K. S. W. Sing.

Cramp, William Addison, B.Sc. (Lond.). British. 2, Sunnyside, Blythe Hill, Catford, London, S.E.6. Research Student at Chelsea Polytechnic. *Signed by:* M. K. Pradhan, J. F. McGhie.

Cressey, Stanley James. British. Frankscroft, Farningham, Kent. Dry Cleaning Manager. *Signed by:* A. Greenwood, S. Elliott.

Crowder, John Robert, B.Sc. (Glas.). British. 24, Mansefield Road, Clarkston, Glasgow. Research Student at The University, Glasgow. *Signed by:* M. F. Grundon, A. D. Jarrett.

Dave, Jatashanker Sadashiv, Ph.D. (Lond.). Indian. Teredesai Building, Hathi Pole, Baroda, India. Lecturer at The University of Baroda. *Signed by:* M. J. S. Dewar, R. Pettit.

Dobson, Norman Alexander, B.Sc. (Glas.). British. 55, Eglantine Avenue, Lisburn Road, Belfast, N. Ireland. Research Student. *Signed by:* R. G. R. Bacon, R. A. Raphael.

Downing, Raymond John. British. 44, Victoria Street, Willenhall, Staffs. Undergraduate at Balliol College, Oxford. *Signed by:* L. A. K. Staveley, W. A. Waters.

Egenes, Raymond John Jewell, B.Sc.Tech. (Natal). South African. 171, Umhlanga Rocks Drive, Durban North, Durban, Natal, S. Africa. Lecturer at The University of Natal. *Signed by:* W. G. Wright, E. A. Hartley, H. A. Candy.

Ellis, Keith. British. 19, Heatherside Road, West Ewell, Surrey. Undergraduate at Cambridge University. *Signed by:* W. G. Palmer, F. B. Kipping.

Fallab, Silvio Arthur, D.Ph. (Basel). Swiss. Anstalt für Anorg. Chemie, Spitalstrasse 51, Basel, Switzerland. Scientific Assistant. *Signed by:* C. A. Grob, P. Läuger.

Feldman, William Ray, B.Sc. (Akron). American. 238, Prospect Street, New Haven, Connecticut, U.S.A. Student. *Signed by:* C. N. Matthews, E. H. White.

Field, Ronald. British. 2, New Council Houses, Station Road, Gt. Billing, Northampton. Sewage Works Chemist. *Signed by:* R. Hemming, D. G. Lewis.

Foster, Michael Antony. British. 796, Thornton Road, Bradford 8, Yorks. Undergraduate at Balliol College, Oxford. *Signed by:* R. E. Richards, W. A. Waters.

Greenbaum, Michael A., B.A. and M.S. (New York). American. 1239, Madison Avenue, New York 28, New York, U.S.A. Teaching Assistant at Yale University. *Signed by:* A. K. Hoffmann, J. E. H. Hancock.

Haines, Peter John. British. 27, Palewell Park, East Sheen, London, S.W.14. Student at Chelsea Polytechnic. *Signed by:* J. F. J. Dippy, A. M. James.

Hall, Ronald Walter. British. 76, Lymington Road, Dagenham, Essex. Industrial Chemist. *Signed by:* R. J. Callow, W. P. Kemp.

Halpern, Jack, B.Sc. and Ph.D. (McGill.). Canadian. Department of Metallurgy, University of British Columbia, Vancouver, B.C., Canada. Assistant Professor at The University of British Columbia. *Signed by:* R. H. Wright, J. D. H. Strickland.

Harper, Terrence Jack. British. Aldwyn, Bowens Hill, Coleford, Glos. Student at Lincoln College, Oxford. *Signed by:* L. A. K. Staveley, R. E. Richards.

Hayler, David Edward. British. Goringlee Cottage, Coolham, Horsham, Sussex. Student at Oxford University. *Signed by:* L. A. K. Staveley, F. J. Stubbs.

Hazell, Alan Charles. British. 21, Blaise Walk, Sea Mills, Bristol 9. Student. *Signed by:* F. H. Pollard, P. Woodward.

Hollingshead, Sheila, B.Sc. (Lond.). British. 189, Turner Bridge Road, Tonge Moor, Bolton, Lancs. Research Student at Manchester College of Technology. *Signed by:* H. N. Rydon, P. C. Crofts.

Holt, John James, B.Sc. (Lond.). British. 57, Yeading Avenue, Harrow, Middlesex. Chemist. *Signed by:* B. C. L. Summers, M. C. Schaul, A. J. Amos.

Humphreys, Jonathan. British. 72, Santon Way, Seascale, Cumberland. Student. *Signed by:* L. A. K. Staveley, D. L. Hammick.

Hutchinson, The Hon. **Mark Hely.** British. Knocklofty, Clonmel, Ireland. Student at Oxford University. *Signed by:* L. A. K. Staveley, L. E. Sutton.

Ibrahim, Abdel Hamid, B.Sc. (Lond.). Sudanese. 32, Rutland Gate, London, S.W.7. Student at Imperial College. *Signed by:* A. G. Pollard, Brynmor Jones.

Ironside, Colin Taylor. British. Logie, Linwood Road, Paisley, Renfrewshire. Student. *Signed by:* S. H. Tucker, C. Buchanan.

Jacques, James Keith. British. 13, Grosvenor Road, Handsworth Wood, Birmingham 20. Student at The Queen's College, Oxford. *Signed by:* L. A. K. Staveley, J. K. Linnett.

Kearney, Patrick Aloysius, B.Sc. (Galway). Irish. Killyconnan, Stradone, Co. Cavan, Ireland. Assistant Lecturer. *Signed by:* P. O'Colla, E. E. Lee.

Leach, Anthony David. British. 63, Rosemary Avenue, West Molesey, Surrey. Undergraduate at London University. *Signed by:* J. F. McGhie, J. F. J. Dippy.

Leane, John Bryant. British. Highlands, Gomshall, Nr. Guildford, Surrey. Undergraduate. *Signed by:* L. A. K. Staveley, R. E. Richards.

Ledger, Warren Albert, B.Sc. (Lond.). British. 22, Balmoral Road, Northampton. Works Chemist. *Signed by:* D. R. W. Bell, W. Siddall.

Letham, David Stuart, M.Sc. (New Zealand). British. 1, Laburnum Grove, Francis Road, Edgbaston, Birmingham 16. Research Student at The University, Birmingham. *Signed by:* J. C. Tatlow, M. Kapel.

Littler, John Samuel. British. 8, Appleton Gate, Newark, Notts. Undergraduate. *Signed by:* L. A. K. Staveley, W. A. Waters.

Lyle, Samuel James, M.Sc. (Q.U.B.). British. Ballyrobert, Craigavad, Co. Down, N. Ireland. Research Student. *Signed by:* R. G. R. Bacon, A. R. Pinder.

McConnell, Peter. British. 55 Chartfield Avenue, Putney Hill, London, S.W.15. Undergraduate at Pembroke College, Oxford. *Signed by:* L. A. K. Staveley, R. J. P. Williams.

McCorkindale, Norman James, B.Sc. (Glas.). British. 99, Dixon Road, Glasgow, S.2. Research Student. *Signed by:* A. D. Jarrett, J. K. Sutherland.

McGrath, William Desmond, B.Sc. (Q.U.B.). British. 32, Keswick Road, East Putney, London S.W.15. Research Student at Imperial College. *Signed by:* A. R. Ubbelohde, J. C. McCoubrey.

Mathewes, David Andrew, jun. B.S. (Davidson Coll.). American. Box 306, Hickory, North Carolina, U.S.A. Graduate Student. *Signed by:* W. E. McEwen, C. A. VanderWerf.

Mattok, George Lionel, B.Sc. (Wales). British. 51, Laurel Crescent, Rush Green, Romford, Essex. Research Student. *Signed by:* A. G. Evans, G. O. Phillips.

Mazur, Yehuda, M.Sc. (Jerusalem), Dr.Sc.Tech. (Zurich). Israeli. Weizmann Institute of Science, Rehovoth, Israel. Research Chemist. *Signed by:* G. T. Newbold, F. S. Spring, J. McLean.

Mill, George Stewart, Ph.D. (Lond.). British. 18, Dalkeith Avenue, Bilton, Rugby, Warwickshire. Research Student, Queen Mary College. *Signed by:* D. C. Jones, D. W. McKee.

Morfee, Ronald George Samuel. British. New College, Oxford. Undergraduate. *Signed by:* L. A. K. Staveley, S. G. P. Plant.

Newill, David William. British. 187, Higham Lane, Nuneaton, Warwickshire. Technical Representative with Dunlop Special Products, Ltd. *Signed by:* G. A. Heath, W. E. Wright, R. F. K. Meredith.

Nightingale, Ian Ritchie, B.Sc. (Lond.). British. 18, New Beacon Road, Grantham, Lincs. Research Student at University College, Leicester. *Signed by:* L. Hunter, F. R. Shaw.

Oakey, Robert Edwin, B.Sc. (Dunelm). British. 6, Danum Avenue, Thirsk, Yorks. Student. *Signed by:* W. F. K. Wynne-Jones, F. J. McQuillin.

Petterson, Robert Carlyle, B.S. (Maine). American. 3443, Hermosa Avenue, Hermosa Beach, California, U.S.A. Student and Industrial Chemist. *Signed by:* M. C. Kloetzel, D. R. Hogg.

Plapinger, Robert E., B.S. (New York), Ph.D. (Maryland). American. 15, Oak Grove Drive, Baltimore 20, Maryland, U.S.A. Research Chemist at Chemical Corps Medical Laboratories, Army Chemical Center, Maryland. *Signed by:* G. Gilbert, R. Swidler.

Powell, John William. British. 8, St. Loyes Road, Exeter, Devon. Student at New College, Oxford. *Signed by:* L. A. K. Staveley, A. S. Bailey.

Radford, Peter John Mayhew. British. The Lodge, Glenwood, Butlers Dene Road, Woldingham, Surrey. Assistant Works Manager. *Signed by:* J. H. Semark, A. M. B. Whitaker.

Redstone, Michael Samuel. British. 13, Northwick Circle, Kenton, Harrow, Middlesex. Student at Pembroke College, Oxford. *Signed by:* L. A. K. Staveley, R. F. Barrow.

Reid, Robert William. British. 38, Firthcliffe Road, Liversedge, Yorks. Student. *Signed by:* L. A. K. Staveley, D. A. Long.

Rendell, David Arthur Edgar. British. 63, Green Road, Headington Quarry, Oxford. Student. *Signed by:* L. A. K. Staveley, L. A. Woodward.

Roe, Michael. British. 18, Allen Road, Northampton. Student. *Signed by:* L. A. K. Staveley, J. A. Barltrop.

Sanderson, Phyllis Mary, B.Sc. and Ph.D. (Lond.). British. 4, Lansdowne Terrace, London, W.C.1. Lecturer. *Signed by:* A. Ratcliffe, F. Kurzer.

Saville, Graham. British. 9, Lodge Avenue, Elland, Yorks. Student at Oxford University. *Signed by:* L. A. K. Staveley, H. Irving.

Scardiglia, Franco, B.S. (Ill.). American. 3673, W. Grand Avenue, Chicago 51, Illinois, U.S.A. Graduate Student. *Signed by:* E. F. Jenny, E. J. Smutny.

Seaman, Jack William Arthur, B.Sc. (Lond.), A.R.I.C. British. 63, Bradley Road, Slough, Bucks. Chief Chemist at Starch Products Ltd., Slough. *Signed by:* W. E. Adams, R. L. Wickens.

Senior, Alwyn, B.Sc. (Birm.), Ph.D. (Cantab.). British. 38, Trinity Street, Cambridge. Research Chemist. *Signed by:* F. G. Mann, F. H. Newth.

Sewell, Peter Roy, B.Sc. (Lond.), A.R.I.C. British. 48, Beresford Avenue, Foleshill, Coventry. Research Student at Birmingham University. *Signed by:* J. C. Tatlow, W. G. P. Robertson.

Shunk, Clifford H., Ph.D. (Wisconsin). American. Merck and Co. Inc., Organic and Biological Division, Rahway, New Jersey, U.S.A. Chemist. *Signed by:* R. P. Graber, E. F. Rogers.

Singer, George Harold. British. Jesus College, Oxford. Undergraduate. *Signed by:* L. A. K. Staveley, L. A. Woodward.

Smith, John David. British. 3, Redcar Road, Guisborough, Yorks. Student at Cambridge University. *Signed by:* J. N. Agar, P. Maitland.

Swallow, Douglas Lintin, B.A. (Oxon.). British. 34, Cottage Lane, Gamesley, Glossop, Derbyshire. Research Student. *Signed by:* L. A. K. Staveley, A. S. Bailey.

Taylor, John Watson, M.Sc. and Ph.D. (Manc.). British. 12, Wood Lane, Timperley, Cheshire. Physical chemistry research. *Signed by:* J. B. M. Herbert, H. A. Skinner.

Tinsley, Robert Charles Noel. British. Netherwood, Cottingley Drive, Bingley, W. Yorks. Chemistry Student at Oxford University. *Signed by:* L. A. K. Staveley, D. Ll. Hammick.

Tillotson, Michael James Lever. British. 78, Bidston Road, Birkenhead. Student. *Signed by:* L. A. K. Staveley, S. G. P. Plant.

Toppin, Archibald, B.Sc. (Glas.). British. 54, Cadder Road, Maryhill, Glasgow, N.W. Science Master at St. Augustine's Senior Secondary School, Glasgow, N. *Signed by:* J. P. Braidwood, A. R. Chambers.

Tsai, Lin, Ph.D. (Florida). Chinese. Department of Chemistry, Ohio State University, Columbus 10, Ohio, U.S.A. Research Associate. *Signed by:* Z. B. Papanastassiou, R. C. Anderson.

Vahora, Adambhai Ahmedbhai, B.Sc.Tech. (Bombay). Indian. 3, Halsey Street, London, S.W.3. Research Student at Chelsea School of Pharmacy. *Signed by :* A. H. Beckett, N. J. Harper.

Van Krevelen, Dirk Willem, Dr.Sc. (Delft.). Dutch. c/o Bibliotheek Staatsmijnen in Limburg, Centraal Laboratorium, Geleen, The Netherlands. Professor of Fuel Technology at The University of Technology, Delft. *Signed by :* R. H. Griffith, A. Parker.

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4846. "The stability of the three-co-ordinated thiourea complex of the silver ion." By W. S. Fyfe.

5456. "Compounds containing sulphur chromophores. Part I. The action of bases on heterocyclic sulphide quaternary salts." By Edward B. Knott.

5457. "Compounds containing sulphur chromophores. Part II. Attempts to prepare sulphide analogues of *mero*cyanines." By E. B. Knott and R. A. Jeffreys.

5458. "Compounds containing sulphur chromophores. Part III. Experiments on the synthesis of ionic dyes." By Edward B. Knott.

5459. "Compounds containing sulphur chromophores. Part IV. Derivatives of heterocyclic methylene bases." By Edward B. Knott.

5630. "The behaviour of 1 : 1 : 1 : 3 : 3 : 3-hexachloropropan-2-ol with inorganic non-metal halides." By W. Gerrard and B. K. Howe.

5636. "Steroids and Walden inversion. Part XX. A kinetic study of the acetolysis of cholesteryl bromide." By R. H. Davies, Sylvia Meecham, and C. W. Shoppee.

5709. "The preparation of some heterocyclic sulphur compounds as possible anthelmintics." By Alexander Mackie and Anand L. Misra.

5710. "Oxidation of some enediols with selenium dioxide." By J. R. Holker.

5715. "Proton-acceptor properties of azulene." By Albert Wassermann.

5719. "Oxygen exchange and the Walden inversion in *sec.*-butyl alcohol." By C. A. Bunton, (Mrs.) Alicja Konasiewicz, and D. R. Llewellyn.

5731. "The constitution of ψ-santonin. Part IX. Investigations into the position of the double bond." By N. M. Chopra, Wesley Cocker, B. E. Cross, J. T. Edward, D. H. Hayes, and H. P. Hutchison.

5750. "The reactivity of *p*-methylbenzyl radicals. A novel application of the kinetic isotope effect." By J. I. G. Cadogan, V. Gold, and D. P. N. Satchell.

5766. "Studies in the pyrolysis of organic bromides. Part I. The kinetics of the decomposition of allyl bromide." By Allan Maccoll.

5767. "Studies in the pyrolysis of organic bromides. Part II. The pyrolysis of *n*-propyl bromide." By P. J. Agius and Allan Maccoll.

5768. "Studies in the pyrolysis of organic bromides. Part III. The pyrolysis of *iso*-propyl bromide." By Allan Maccoll and P. Thomas.

5771. "Isotopic exchange of copper between cupric nitrate and copper metal." By J. F. Duncan and B. W. Oakley.

5775. "Hydrolytic decomposition of esters of nitric acid. Part IV. Acid hydrolysis, and the effects of change in the nucleophilic reagent on the S_N and E_{CO} reactions." By John W. Baker and A. J. Neale.

5776. "Hydrolytic decomposition of esters of nitric acid. Part V. The effects of structural changes in aralphyl nitrates on the S_N and E_{CO} reactions." By John W. Baker and T. G. Heggs.

5777. "The polarographic reduction of tervalent arsenic in non-complex-forming media." By D. A. Everest and G. W. Finch.

5783. "The hydrolysis of titanium tetraethoxide." By D. C. BRADLEY, R. GAZE, and W. WARDLAW.

5784. "Syntheses using monoketals of *cyclo*hexane-1 : 2-dione. Part II. 2-Ethynyl-2-hydroxy*cyclo*hexane-1-*spiro*-2′-(1′ : 3′-dioxolan), the corresponding oxathiolan and dithiolan and some transformation products thereof." By (MRS.) R. R. JAEGER and HERCHEL SMITH.

5785. "The exchange of oxygen between alcohols and water. Part I. Rates of carbonium ion formation and decomposition in acidic aqueous solutions of *tert.*-butanol." By I. DOSTROVSKY and F. S. KLEIN.

5787. "Sorption and reactivity of N_2O and NO in crystalline and amorphous siliceous sorbents." By W. E. ADDISON and R. M. BARRER.

5792. "Normal alkoxides of quinquevalent tantalum." By D. C. BRADLEY, W. WARDLAW, and (MISS) ALICE WHITLEY.

5793. "The hydrolysis of acetic anhydride. Part IV. Catalysis by hydrochloric acid and the hydrolysis of acetyl chloride." By V. GOLD and J. HILTON.

5794. "The hydrolysis of acetic anhydride. Part V. Catalysis by strong acids." By V. GOLD and J. HILTON.

5796. "Chelate systems. Part III. Infra-red spectra of flavanones and flavones." By B. L. SHAW and T. H. SIMPSON.

5797. "Cyclic amidines. Part III. 2-Acylamino-4-alkoxyquinolines." By R. HARDMAN and M. W. PARTRIDGE.

5802. "The aliphatic hydroxylamines. Part I. Preparation." By M. A. THOROLD ROGERS.

5803. "The thermal decomposition of ammonium dichromate." By DUNCAN TAYLOR.

5804. "The synthesis of some *N*-hydroxy-imides." By D. E. AMES and T. F. GREY.

5805. "The absorption spectra in relation to the chemical reactivity of some halogeno-aromatic compounds." By F. SMITH and LILIAN M. TURTON.

5806. "Decompositions of mixed diazonium fluoroborates." By J. C. BRUNTON and H. SUSCHITZKY.

5810. "Some reactions of ethyl cyanoacetate." By D. G. I. FELTON.

5813. "Lactones. Part I. A novel method for the conversion of phthalides into phthalaldehydic acids." By JOHN BLAIR, J. J. BROWN, and G. T. NEWBOLD.

5814. "The structure of bacterial polyglutamic acid." By S. G. WALEY.

5817. "The synthesis of acyl phosphates in aqueous solution." By A. W. D. AVISON.

5818. "The alkali-soluble polysaccharides of the lichen *Cladonia alpestris* (reindeer moss)." By G. O. ASPINALL, E. L. HIRST, and (MRS.) MARGARET WARBURTON.

5819. Addendum: "Chemical action of ionizing radiations in aqueous solutions. Part XIII. Absolute yield of the ferrous sulphate dosimeter." By F. T. FARMER, T. RIGG, and J. WEISS.

5820. "The chemistry of silica surfaces." By P. F. HOLT and D. T. KING.

5821. "The configuration at $C_{(25)}$ in the natural spirostan sapogenins." By V. H. T. JAMES.

5824. "The acylation of 3-methylcytosine." By G. W. KENNER, C. B. REESE, and SIR ALEXANDER TODD.

5825. "Some reactions of *cyclo*propane and a comparison with the lower olefins. Part I. Introduction and reaction with strong acids." By C. D. LAWRENCE and C. F. H. TIPPER.

5827. "2 : 3-Dihydro-3-oxobenz-1 : 4-oxazines." By J. D. LOUDON and J. OGG.

5828. "*cyclo*Laudenol, a triterpenoid alcohol from opium." By H. R. BENTLEY, J. A. HENRY, D. S. IRVINE, D. MUKERJI, and F. S. SPRING.

5829. "Studies on biological methylation. Part XV. The formation of dimethyl selenide in presence of D- and L-methionine or of thetins, all containing the $^{14}CH_3$ group." By PHILIP B. DRANSFIELD and FREDERICK CHALLENGER.

5830. "The interaction of calcium ions with some citrate buffers: A correction." By C. W. DAVIES and B. E. HOYLE.

5831. "The chemistry of extractives from hardwoods. Part XXI. The structure of eperuic acid." By F. E. KING and GURNOS JONES.

5832. "Dithiobiurets. Part I. Some 1- and 1 : 5-substituted derivatives." By A. E. S. FAIRFULL and D. A. PEAK.

5833. "Dithiobiurets. Part II. Some cyclic derivatives." By A. E. S. FAIRFULL and D. A. PEAK.

5837. "A synthesis of (±)-phellandral." By D. T. C. GILLESPIE, P. R. JEFFERIES, A. KILLEN MACBETH, and M. J. THOMPSON.

5839. "A method of reducing phenols to aromatic hydrocarbons." By G. W. KENNER and N. R. WILLIAMS.

5840. "Nucleotides. Part XXX. Mononucleotides derived from deoxyadenosine and deoxyguanosine." By D. H. HAYES, A. M. MICHELSON, and SIR ALEXANDER TODD.

5841. "Deoxyribonucleosides and related compounds. Part V. *cyclo*Thymidines and other thymidine derivatives. The configuration at the glycosidic centre in thymidine." By A. M. MICHELSON and SIR ALEXANDER TODD.

5849. "Ring expansion of 2-benzylidenecoumaran-3-ones: a synthesis of flavones." By D. M. FITZGERALD, J. F. O'SULLIVAN, (MRS.) E. M. PHILBIN, and T. S. WHEELER.

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5861. "Some complex oxyfluorides of septivalent rhenium." By R. D. PEACOCK.

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[UNITED STATES] *National Research Council. Division of Physical Sciences. Committee on Nuclear Science. Subcommittee on Radiobiology.* Basic mechanisms in radiobiology. II. Physical and chemical aspects. Proceedings of an informal conference held . . . May 7—9, 1953. Washington, D.C. 1953. pp. vii + 145. ill. The Council. $1. (*Recd.* 8/12/54.)

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PROCEEDINGS
OF THE
CHEMICAL SOCIETY

ANNIVERSARY MEETINGS

Wednesday, March 30th—Friday, April 1st, 1955

Full details of the Anniversary Meetings to be held in London are being issued as a separate notice.

SCIENTIFIC MEETINGS DURING APRIL, 1955

MANCHESTER.

Thursday, April 21*st*, 1955, *at* 10.30 *a.m.*

One-day Symposium, **Organometallic Compounds.** Speakers to include: Professor K. Siegler, Dr. E. A. Braude, Professor G. E. Coates, Dr. J. Chatt, Dr. F. G. Mann, Dr. M. C. Whiting. Joint Meeting with the Royal Institute of Chemistry, the Society of Chemical Industry, and the Institute of Petroleum. To be held in the Chemistry Lecture Theatre, the University.

NORTHERN IRELAND.

Tuesday, April 26*th*, 1955, *at* 7.45 *p.m.*

Meeting for the reading of Original Papers. To be held in the Chemistry Lecture Theatre, Queen's University, Belfast.

ST. ANDREWS AND DUNDEE.

Friday, April 15*th*, 1955, *at* 5.15 *p.m.*

Lecture, **Polymerisation of the Vinyl Ethers,** by Professor D. D. Eley, M.Sc., Ph.D. Joint meeting with the University Chemical Society, to be held in the Chemistry Department, the University, St. Andrews.

OFFICIAL ANNOUNCEMENTS

DEATHS.

The Council regrets to announce the deaths of the following Fellows:

	Elected.	Died.
Sir Shanti Swarupa Bhatnagar (New Delhi)	Dec. 3rd, 1920.	Jan. 1st, 1955.
Llewellyn John Davies (Penarth)	June 18th, 1918.	Dec. 26th, 1954.
Samuel Ernest Groves (Gateshead)	May 4th, 1905.	Dec. 23rd, 1954.
John Poinier Rogers (Redruth)	June 21st, 1928.	Dec. 10th, 1954.
Henry Terrey (London, W.C.1) (C. 1928/31)	Feb. 18th, 1915.	Dec. 24th, 1954.

CONGRATULATIONS.

The President has conveyed the congratulations of the Society to Owen Haddon Wansbrough-Jones on the award of the K.B.E. in the New Year Honours List.

ACKNOWLEDGMENTS.

Acknowledgment is made of gifts of the Society's publications from Mr. J. W. Reidy and Mr. F. Thomas.

ELECTION OF NEW FELLOWS.

The following 82 candidates were elected Fellows of the Society on January 20th, 1955:

Roy Melville Adams.
John Addy.
Leslie Ernest Addy.
Geoffrey Robert Ames.
Kenneth Harding Ansell.
Walter Vernon Barnes.
Yvonne Marion Beasley.
Ernest Thompson Blues.
Robert Boschan.
Keith Bradshaw.
Per Bro.
Reginald Wilson Broadbent.
Frank Walter Brown.
Clifford Reginald Chessman.
Howard Charles Clark.
David Harold Cole.
John Frank Corbett.
Jeffrey James Cox.
Mary Davies.
Norman Robert Davies.
Trevor Davies.
Douglas Chester Eagles.
Brian Anthony Fox.
Glenn Harold Foxley.
Siegfried Galandauer.
Andrea Gandini.
John Flett Garden.
Charley Gustafsson.
Robert Gerald Guy.
Robert Markham Haines.
Raymond Ledingham Hardie.
Norman Frank Hayes.
John Hamon Massey Hill.
Ian Geoffrey Hinton.
Derek Horton.
James William Howison.
Keith Wood Humphreys.
John Hugh Isaacson.
Donald Hugh Jenkinson.
Keith Robert Jennings.
Albert Stanley Jones.
Gottfried Gustav Klee.
Wsewolod Korytnyk.
Cheuk Man Lee.
John Frederick Lee.
Patrick Gerald Noel Leonard.
Richard George Lingard.
William Joseph Linn.
Joyce Colquhoun Lockhart.
Richard Norman McDonald.
James William McFarland.
Edward McLaughlin.
David Malcolm McMahon.
Dhirendra Nath Maitra.
Martin John Marcus.
Brian Martin.
Gerald Mechanic.
Alan Melmoth.
Alfred Leonard Mills.
Thomas Mole.
Gamal El Din Mohamed Ahmed Moussa.
Nigel Malcolm St. John Murphy.
Derek Charles Nonhebel.
William Phillip Norris.
Mario Onyszchuk.
Donald Ian Packham.
Alfred Packter.
Shrikrishna Janardan Patki.
George Leonard Reed.
Russell Reed.
Herman G. Richey.
Arthur Richmond.
Robert Alexander Rust.
Roy John Sampson.
John Philip Simons.
Derrick Stewart Swift.
Michael Taylor.
Morice William Thompson.
Henry Rudd Thornton.
John Ernest Tomlin.
Timothy Fossett Wheatley.
Christopher John Willis.

PROCEEDINGS OF THE SYMPOSIUM ON CO-ORDINATION CHEMISTRY—COPENHAGEN, AUGUST, 1953.

A report of this Symposium has now been published by the Danish Chemical Society. It contains thirty-three papers (twenty-five in English and eight in German). The authors include: A. W. Adamson, R. W. Asmussen, J. Bjerrum, N. Bjerrum, H. Bode, J. Chatt, van Eck, S. Fronaeus, P. George, K. Gleu (summary only), N. N. Greenwood, W. L. Groeneveld, K. A. Jensen, W. Klemm, J. Koefoed, N. Konopik, H. Krebs, W. L. Latimer, I. Leben, F. G. Mann, R. Nänäsen, R. Nast, L. E. Orgel, L. Pauling (summary only), H. M. Powell, O. Schmitz-DuMont, R. Scholder, F. Seel, L. G. Sillen, L. E. Sutton, B. Tezak, B. West, and R. J. P. Williams. A report of the discussion is also included. The publication price is **$3**, but Fellows of the Chemical Society may obtain copies at the special price of 15s. on application to the General Secretary, The Chemical Society, Burlington House, London, W.1. Fellows are requested to enclose a remittance with their orders.

Non-Fellows should not write to the Chemical Society but to the Secretary, Kemisk Forening, Østervoldgade 5, Copenhagen K, Denmark.

MINUTES OF SCIENTIFIC MEETINGS

Minutes of a

SCIENTIFIC MEETING

held in the Large Chemistry Lecture Theatre, Imperial College of Science and Technology, South Kensington, London, S.W.7, on Thursday, January 20th, 1955, at 7.30 p.m.

The President, PROFESSOR W. WARDLAW, C.B.E., D.Sc., F.R.I.C., was in the Chair.

MINUTES.

The Minutes of the Scientific Meeting held at Burlington House on December 16th, 1954, were read, and were confirmed and signed.

FORMAL ADMISSION OF FELLOWS.

The following were admitted Fellows of the Society: G. F. Phillips, C. L. Leese, D. Daniel, W. Slough, D. R. Fellows, R. J. Townsend, Kenneth R. Hanson, A. D. Buckingham, Howard N. Schmeising, Paolini Leonello, M. A. Kazi, G. B. Porter, D. M. Butcher.

TILDEN LECTURE.

The President called upon Professor H. C. Longuet-Higgins to deliver the Tilden Lecture entitled "The Rôle of the π-Electron in Aromatic Chemistry." At the conclusion on the Lecture, a vote of thanks to Professor Longuet-Higgins, proposed by Mr. R. P. Bell, was carried with acclamation.

LIST OF APPLICATIONS FOR FELLOWSHIP

(*Fellows wishing to lodge objection to the election of these candidates should communicate with the Honorary Secretaries within ten days of the date of publication of the* Journal *for February, 1955. Such objections will be treated as confidential. The forms of application are available in the Library.*)

Arnold, Robin, M.Sc. and Ph.D. (Witwatersrand), A.R.I.C. South African. Department of Chemistry, University of Cape Town, Rondebosch, Cape Town. Lecturer. *Signed by:* F. G. Holliman, A. H. Spong, J. R. Nunn.

Bartram, Charles Alan, B.Sc. (Lond.). British. 63, Stirling Grove, Clifton Estate, Nottingham. Research Chemist. *Signed by:* W. F. Short, D. A. Peak.

Beall, Ivor Donovan, B.Sc. (Lond.), A.R.I.C. British. 19, Beresford Street, Stoke, Plymouth, Devon. Chief Works, Chemist. *Signed by:* E. R. Braithwaite, D. R. Glasson.

Beckwith, Athelstan Laurence Johnson, B.Sc. (Western Australia). Australian. Balliol College, Oxford. Overseas Research Student. *Signed by:* W. A. Waters, H. Smith.

Bekoe, Daniel Adzei, B.Sc. (Lond.). British. Balliol College, Oxford. Chemical Research Student *Signed by:* H. M. Powell, L. E. Sutton.

Bil, Milos, R.Nat.Dr. (Prague). Czech. Sadova 7, Usti n. Labem, Czechoslovakia. Chemical Technologist. *Signed by:* J. Weigner, F. Panzner.

Cameron, Margaret Anne Mercer, B.Sc. (Glas.). British. 7, Corsewall Avenue, North Mount Vernon, Glasgow, E.2. Research Student at Glasgow University. *Signed by:* C. Buchanan, J. D. Loudon.

Clay, Peter Gillis. British. 64, Linskill Terrace, North Shields, Northumberland. Student at King's College, Durham. *Signed by:* L. Seal, G. A. Swan.

Coats, Norman Alfred. British. 63, Southill Road, Parkstone, Dorset. Student at Oxford University. *Signed by:* L. A. K. Staveley, F. M. Brewer.

Coenders, Albert. Dutch. 108, Corringway, Ealing, W.5. Assistant Works Manager. *Signed by:* H. E. Slaap, A. Krajkeman.

Cohen, Theodore, B.S. (Tufts Coll.). American. 1071 West 30th Street, Los Angeles 7, California, U.S.A. Graduate Student at University of Southern California. *Signed by:* D. R. Hogg, J. A. Berson.

Cole, Charles George Bernard, B.Sc. (Cape Town). South African. Byletts, P. O. Kwelegha, East London, South Africa. Chemist. *Signed by:* F. G. Holliman, M. Lamchen, F. Sebba.

Cotterill, Colin Bertie, B.Sc. (Nott.). British. S.H.A.P.E. Signal Squadron, British Supporting Unit, B.F.P.O.6 (Paris). National Serviceman. *Signed by:* K. G. Mason, J. H. Gilks.

Crowley, Kevin John, B.A. (Oxon.). British. Cornelscourt, Foxrock, Co. Dublin, Eire. Research Student at Oxford University. *Signed by:* N. Polgar, R. Brettle.

Davidson, David. British. 141, Westbury Road, Bristol 9. Research Student. *Signed by:* A. R. Battersby, G. C. Davidson.

Davies, Anthony Geoffrey, B.Sc. (Wales). British. 23, Brondeg, Manselton, Swansea, Glam. Research Student at University College, Swansea. *Signed by:* K. W. Sykes, R. H. Davies.

Dent, Lesley Scott, B.A. (Cantab.). British. 102, Clifton Road, Aberdeen. Assistant at University of Aberdeen. *Signed by:* H. F. W. Taylor, R. H. Thomson.

Dicker, David William, B.Sc. (Manc.). British. 38, Laburnum Road, Denton, Manchester. Research Student at Manchester University. *Signed by:* G. R. Barker, M. C. Whiting.

Dominey, Derek Alan. British. 75, Darby's Lane, Poole, Dorset. Undergraduate at Balliol College, Oxford. *Signed by:* L. A. K. Staveley, W. A. Waters.

Edgington, David Norman. British. 65, Divinity Road, Oxford. Student at Oxford University. *Signed by:* L. A. K. Staveley, F. M. Brewer.

Everitt, Pauline Marjorie, B.Sc. (Lond.). British. 30, Clarence Gate Gardens, Glentworth Street, London, N.W.1. Research Student. *Signed by:* E. E. Turner, D. M. Hall.

Eyres, Alan Richard. British. 42, Australian Avenue, Salisbury, Wilts. Student. *Signed by:* L. A. K. Staveley, D. A. Long.

Field, Brian Orlando. British. 15, Benson Street, Little Harwood, Blackburn, Lancs. Student at Durham University. *Signed by:* J. Grundy, A. Walton.

Grace, John Alan, B.Sc. (Southampton). British. 109, Canford Cliffs Road, Canford Cliffs, Bournemouth, Hants. Research Student. *Signed by:* N. B. Chapman, M. C. R. Symons.

Hall, George E., Ph.D. (Yale). American. Department of Chemistry, Mount Holyoke College, South Hadley, Massachusetts, U.S.A. Associate Professor of Chemistry. *Signed by:* E. J. Smutny, E. F. Jenny.

Hirschmann, Hans, M.D. (Basel), Ph.D. (Columbia). American. Department of Medicine, Lakeside Hospital, Cleveland 6, Ohio, U.S.A. Associate Professor at Western Reserve University. *Signed by:* J. W. Corcoran, S. H. Pomerantz, R. F. Hirschmann.

Hollows, Frank Brian, B.Sc. (Wales), A.R.I.C. British. 146, South Mossley Hill Road, Liverpool 19. Research Student at the University College of N. Wales. *Signed by:* J. E. McKail, W. Rogie Angus.

Holt, Anthony. British. 1, West Court, North Wembley, Middlesex. Undergraduate at Birmingham University. *Signed by:* J. C. Tatlow, A. Fairhurst.

Johnson, Michael Daintry, B.Sc. (Southampton). British. Manorbier, Cobden Avenue, Southampton. Research Student at Southampton University. *Signed by:* N. B. Chapman, R. E. Parker.

Kurath, J. Paul, Dr.Sc.Nat. (E.T.H. Zürich). Swiss. Strong Memorial Hospital, 260, Crittenden Boulevard, Rochester 20, N.Y., U.S.A. Research Chemist. *Signed by:* B. D. Astill, G. M. K. Hughes.

Kushinsky, Stanley, B.S. (City Coll. of New York), M.A. (Columbia). American. 222, Maple Avenue, Shrewsbury, Massachusetts, U.S.A. Ph.D. Candidate at Boston University. *Signed by:* N. L. McNiven, H. Levy.

Leyshon, Howard Morgan Edward, A.M.Inst.Gas E. British. 62, Chandos Avenue, Roundhay, Leeds, 8. Manager to Metropolitan Meters, Ltd. *Signed by:* A. H. Dodd, P. A. Briscoe, J. W. Wood.

Lipp, Maria, Dr.Ing. German. Rhein Westf. Techn. Hoschschule, Aachen, Templergraben 55, Germany. Professor of Organic Chemistry. *Signed by:* E. J. Bourne, J. C. Tatlow.

Lunts, Lawrence Henry Charles, B.Sc. (Sheffield). British. 4, Woodland Grove, Woodthorpe, Nottingham. Research Student. *Signed by:* J. McKenna, H. J. V. Tyrrell.

McEwan, Ian Hugh, B.Sc. (Wales). British. 57, Fidlas Avenue, Llanishen, Cardiff. Research Student. *Signed by:* N. M. Cullinane, S. J. Chard.

Mekler, Arlen B., B.S. (San Jose State Coll.). American. 518, Carroll Avenue, Ames, Iowa, U.S.A. Graduate Instructor in Chemistry at Iowa State College. *Signed by:* T. Stevens, L. H. Liu.

Mertel, Holly Edgar, M.S. (Nevada), Ph.D. (Southern California). American. 31, Roger Avenue, Cranford, New Jersey, U.S.A. Research Chemist at Merck and Co. Inc., Rahway, New Jersey. *Signed by:* D. Y. Curtin, E. E. Harris, J. M. Chemerda.

Miller, David Anderson, B.A. (Oxon.). British. Selwyn, Tudor Avenue, Prestatyn, North Wales. Student. *Signed by:* W. A. Waters, A. Marchant.

Milsted, John, Ph.D. (Bris.). British. 5, Letcombe Avenue, Abingdon, Berks. Research Chemist at Atomic Energy Research Establishment, Harwell. *Signed by:* E. Hesford, G. R. Hall.

Minhaj, Fatima, M.Sc. (Aligarh.). Indian Chemistry Department, Bedford College, London, N.W.1. Student. *Signed by:* D. M. Hall, M. M. Harris.

Moss, Raymond Jackson, B.Sc. (Manc.). British. Chemistry Department, The University, Manchester 13. Research Student. *Signed by:* G. R. Barker, B. B. Millward.

Neptune, William Everett, M.S. and Ph.D. (Oklahoma). American. Department of Physical Science, Oklahoma Baptist University, Shawnee, Oklahoma, U.S.A. Assistant Professor of Chemistry. *Signed by:* K. K. Innes, L. S. Ciereszko.

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Nield, Patrick, M.Sc.Tech. (Manc.). British. Station Road, Scholar Green, Stoke-on-Trent. Research Student. *Signed by:* H. N. Rydon, G. Baddeley.

Norman, Richard Oswald Chandler, B.A. (Oxon.). British. 87, Eynsham Road, Oxford. Research Student at Oxford University. *Signed by:* W. A. Waters, A. H. Turner.

O'Sullivan, John Francis, M.Sc. and Ph.D. (N.U.I.). Irish. 11, Edenvale Road, Ranelagh, Dublin. Research Chemist at M.R.C. Laboratories, Trinity College, Dublin. *Signed by:* D. O'Tuama, J. G. Belton.

Pensom, Croombe Frank. British. 12, Lexham Gardens, London, W.8. Student Assistant, General Electric Co. *Signed by:* J. F. J. Dippy, A. M. James.

Placito, Peter John. British. Wadhurst, Broom Way, Oatlands Park, Weybridge, Surrey. Student. *Signed by:* L. A. K. Staveley, D. Ll. Hammick.

Platou, Jan Eilif Lehm Kahl Stoud. Norwegian. 211, Newhaven Road, Edinburgh, 6. Student at Heriot Watt College. *Signed by:* F. Bell, A. Mackie.

Richards, Nolan Earle, M.Sc. (New Zealand). Department of Chemistry, University of Pennsylvania, Philadelphia 4, Pennsylvania, U.S.A. Student. *Signed by:* L. H. Briggs, B. F. Cain.

Roberts, Hugh Leithead, B.A. (Oxon.). British. Jesus College, Oxford. Research Student. *Signed by:* L. A. K. Staveley, L. A. Woodward.

Robinson, Robert, F.R.I.C. British. c/o International Paints, Ltd., Felling-on-Tyne, Co. Durham. Chief Chemist. *Signed by:* T. A. Banfield, J. K. Blacklock, F. G. Palmer.

Rogers, Ian Henry, B.Sc. (Q.U.B.). British. 1, Gilnahirk Park, Cherryvalley, Belfast, N. Ireland. Assistant Chemist to Blackwood, Morton and Son, Ltd. (Kilmarnock). *Signed by:* R. G. R. Bacon, W. S. Lindsay.

Rosell, Jan Axel William. British. 13, Celtic Avenue, Shortlands, Bromley, Kent. Student. *Signed by:* L. A. K. Staveley, J. A. Barltrop.

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Silberman, Henryk, Ph.D. (Vienna). Australian. 45, Cobham Avenue, Ermington, New South Wales, Australia. Drug Analyst. *Signed by:* A. J. Birch, S. E. Wright.

Sly, James Christopher Phillips, B.Sc. (Wales). British. 12, Penbryn Terrace, Brynmill, Swansea, Glam. Research Student at University College, Swansea. *Signed by:* K. W. Sykes, G. H. R. Summers.

Soddy, Theodore Stephen, M.S. (Detroit). American. Chemistry Department, Iowa State College, Ames, Iowa, U.S.A. Graduate Student. *Signed by:* G. S. Hammond, J. Tanaka.

Stelzer, Isidore. British. 5, Queen's Gardens, London, N.W.4. Student at London University. *Signed by:* M. J. S. Dewar, R. F. Garwood.

Stranks, Donald Richard, M.Sc. and Ph.D. (Melbourne). Australian. School of Chemistry, The University, Leeds, 2. Assistant Lecturer in Radiochemistry. *Signed by:* K. J. Ivin, E. Collinson.

Sullivan, Patrick D., B.S. (Holy Cross Coll.). American. Sterling Chemistry Laboratory, Yale University, New Haven, Connecticut, U.S.A. Graduate Student. *Signed by:* E. H. White, W. von E. Doering, A. K. Hoffmann.

Taylor, Michael Eric Upcott, B.Sc. (Lond.). British. Flat 1, 56, Court Road, Eltham, S.E.9. Research Assistant at London School of Hygiene and Tropical Medicine. *Signed by:* H. Raistrick, C. Ewart Stickings.

Thomas, John Meurig, B.Sc. (Wales). British. 39, Pontardulais Road, Llangennech, Llanelly, Carms. Research Student at Swansea University College. *Signed by:* M. W. Roberts, D. E. Evans.

Thomas, Peter James, B.Sc. (Wales), Ph.D. (Lond.). British. Department of Chemistry, Imperial College, S.W.7. Assistant Lecturer. *Signed by:* R. D. Peacock, J. A. Kitchener.

Topliss, Colin. British. 84, Park View, Oakthorpe, Burton-on-Trent Staffs. Student. *Signed by:* L. A. K. Staveley, D. A. Long.

Toromanoff, Edmond René, Dr.Ing. (Paris). French. 13A, Chauncy Street, Cambridge 38, Massachusetts, U.S.A. Research Fellow at Harvard University. *Signed by:* R. B. Clayton, M. A. Romero.

Trapnell, Barry Maurice Waller, M.A. and Ph.D. (Cantab.). British. Department of Physical and Inorganic Chemistry, The University, Liverpool. Lecturer. *Signed by:* A. K. Holliday, C. F. H. Tipper.

Varadarajan, Srinivasa, M.A. (Madras), M.Sc. (Andhra), Ph.D. (Delhi). Indian. University Chemical Laboratory, Pembroke Street, Cambridge. Overseas Research Scholar. *Signed by:* A. W. Johnson, D. M. Brown.

Whalley, George Raymond, A.R.I.C. British. 9, Llanberis Grove, Nuthall Road, Nottingham. Works Chemist, at Messrs. Gerard Bros. Ltd., Nottingham. *Signed by:* R. J. Fearn, E. Tittensor.

White, Robert Winslow, S.B. (Mass. Inst. of Tech.). American. 17, Raymond Avenue, Somerville 44, Massachusetts, U.S.A. Student. *Signed by:* K. Drake, F. D. Greene.

Wicken, Anthony John, B.Sc. (Cape Town). British. 8, The Crescent, Pinelands, Cape, South Africa. Postgraduate Student. *Signed by:* F. G. Holliman, M. C. B. Hotz, J. R. Nunn.

Yates, John Russell. British. Jesus College, Cambridge. Student. *Signed by:* A. G. Sharpe, W. H. Mills.

UNDER SPECIAL PROVISION APPERTAINING TO CANDIDATES RESIDENT ABROAD.

Bunnag, Yos, M.Sc. (Lond.), A.R.C.S., D.I.C. Thai. Department of Science, Ministry of Industry, Rama VI Road, Bangkok, Thailand. Senior Chemist. *Signed by:* S. Mongkolsuk.

Fugger, Joseph, M.S. and Ph.D. (Pittsburgh). American. 898, East Drive, Menphis 8, Tennessee, U.S.A. Research Chemist at Cellulose Research Division, Buckeye Cotton Oil Co., Tennessee. *Signed by:* A. M. Dowell.

Goldstein, Melvin Joseph, B.A. (Columbia Coll.). American. Department of Chemistry, Yale University, New Haven, Connecticut, U.S.A. Graduate Student. *Signed by:* W. von E. Doering.

Haimsohn, Jerome Newton, M.S. (Polytechnic Inst. of Brooklyn). American. Stauffer Chemical Co., Chauncey, New York, U.S.A. Head of General Chemical Section. *Signed by:* C. G. Overberger.

Hashmi, Manzur-ul-Haque, M.Sc. (Punjab). Pakistani. Physical Chemistry Department, Imperial College of Science and Technology, London, S.W.7. Student. *Signed by:* M. I. D. Chughtai.

Krems, Irving J., M.S. and Ph.D. (Polytechnic Inst. of Brooklyn). American. 3031, Edwin Avenue, Fort Lee, New Jersey, U.S.A. Chemist at Colgate-Palmolive Co., New Jersey. *Signed by:* J. F. Gerecht.

Marks, Henry C., B.A. and Ph.D. (Pennsylvania). American. Wallace and Tiernan Inc., 25, Main Street, Belleville, New Jersey, U.S.A. Director of Laboratory Research. *Signed by:* J. C. Baker.

Nöth, Heinrich, Dr.Rer.Nat. (München). German. (13b), München 25, Waakirchnerstrasse 28/1, Germany. Research Worker. *Signed by:* J. E. F. Evans.

Rajagopalan, Srinivasa, D.Sc. (Andhra), A.R.I.C. Indian. Metzer Strasse, 55, Basel, Switzerland. Lecturer at Andhra University. *Signed by:* T. Reichstein.

Sydor, Walter J., B.S. (Worcester Polytechnic Inst.), Ph.D. (Mass.). American. P.O. Box 76, N. Branch Depot., New Jersey, U.S.A. Development Chemist. *Signed by:* D. W. Hein.

Tamura, Saburo. Japanese. Department of Agricultural Chemistry, The University of Tokyo, Bunkyo-ku, Tokyo, Japan. Assistant Professor. *Signed by:* M. Miyano.

Uyeo, Shojiro, D.Pharm. (Tokyo). Japanese. School of Pharmacy, University of Osaka, Hotarugaike, Toyonaka-shi, Osaka, Japan. Professor of Chemistry. *Signed by:* C. Kawasaki.

Verma, Pramode, M.Sc. (Agra). Indian. Blood Bank Organisation, Burdwan House, Agra, Indian. Scientific and medical research worker at Institut Pasteur, Paris. *Signed by:* I. P. Varshney.

Wolfe, James Richard, jun., B.S. (M.I.T.). American. Department of Chemistry, University of California, Berkeley, California. Graduate Student. *Signed by:* A. Streitwieser.

Yajima, Haruaki. Japanese. 247, Uchida, Toyonaka, Osaka Pref., Japan. Assistant of Pharmacy in Osaka University. *Signed by:* C. Kawasaki.

PAPERS ACCEPTED

(List of Papers accepted between December 30th, 1954, and January 24th, 1955, for publication in the *Journal*.)

Numbers quoted are " Reprint Order Numbers." Reprints may be ordered from the list below, or from the published *Journal* (January 1954 onwards). Orders must be sent to the General Secretary accompanied by a remittance for 5*s*. for each reprint, or by the appropriate number of reprint vouchers. Reprint voucher books may be obtained, price 10*s*. per book of five vouchers available to Fellows and to those who subscribe to the *Journal*. Fellows, but not subscribers, may also obtain books, limited to one per Fellow, containing 30 reprint vouchers at £1 10*s*. per book.

4845. " Complex-ion formation. Part III. The entropies of reaction of the silver and hydrogen ions with some aliphatic amines." By W. S. FYFE.

5137. " The order and mechanism of the isotopic exchange reactions of secondary and tertiary alkyl bromides in anhydrous acetone." By L. J. LE ROUX and E. R. SWART.

5641. " Reactions in boron trifluoride–*n*-butanol–tri-*n*-butyl borate systems." By M. F. LAPPERT.

5711. " Cellular constituents. The chemistry of xanthine oxidase. Part I. The preparation of a crystalline xanthine oxidase from cow's milk." By P. G. AVIS, F. BERGEL, and R. C. BRAY.

5745. " The stabilities of metal chelate compounds formed by some heterocyclic acids. Part I. Studies in aqueous solution." By F. HOLMES and W. R. C. CRIMMIN.

5799. " The acidity function H_0 for solutions of trifluoroacetic acid and trichloroacetic acid in water." By J. E. B. RANDLES and J. M. TEDDER.

5800. " Some compounds related to 1 : 2-dihydro-4-hydroxy-1-oxo-2-phenylphthalazine." By DAVID J. DRAIN and DONALD E. SEYMOUR.

5822. " The chromatography of gases and vapours. Part V. Partition analyses with columns of Silicone 702 and of tritolyl phosphate." By A. B. LITTLEWOOD, C. S. G. PHILLIPS, and D. T. PRICE.

5823. " An addition compound of glyoxal and ethylene glycol." By FRANK S. H. HEAD.

5826. " Organic oxidation processes. Part III. The reaction of lead tetra-acetate with some phenyl ethers." By G. W. K. CAVILL and D. H. SOLOMON.

5834. " The formation of *iso*butenyl radicals from *iso*but-1-enylsilver. Part I." By F. GLOCKLING.

5835. " Elucidation of the mechanism of the Michael condensation with ^{18}O as tracer. Part I. The ' abnormal ' reaction." By DAVID SAMUEL and DAVID GINSBURG.

5836. " The effect of crystallinity on rhythmic precipitation." By A. PACKTER.

5842. " The extraction of indium at macroconcentrations from hydrobromic acid into *iso*butyl methyl ketone and diethyl ether." By H. IRVING and F. J. C. ROSSOTTI.

5843. " The extraction of indium at tracer concentrations from acid–bromide solutions into *iso*butyl methyl ketone." By H. IRVING and F. J. C. ROSSOTTI.

5845. " Preparation of phenothiazine derivatives as possible anthelmintics. Part II." By ALEXANDER MACKIE and ANAND L. MISRA.

5846. " Hydropteridines. Part III. 5 : 6 : 7 : 8-Tetrahydro-4-methylpteridine." By P. R. BROOK and G. R. RAMAGE.

5847. " Heats of combustion and molecular structure. Part III. Diphenylene." By R. C. CASS, H. D. SPRINGALL, and (in part) P. G. QUINCEY.

5852. " Experiments on the synthesis of the pyrethrins. Part IX. The addition of ethyl diazoacetate to sorbic esters." By STANLEY H. HARPER and HUGH W. B. REED.

5855. " Studies on fructosans. Part VI. The degradation of fructosans in aqueous solution." By G. O. ASPINALL and R. G. J. TELFER.

5856. " Gum ghatti (Indian gum). The composition of the gum and the structure of two aldobiouronic acids derived from it." By G. O. ASPINALL, E. L. HIRST, and A. WICKSTRØM.

5858. "α-1 : 4-Glucosans. Part III. The molecular structure of brewer's yeast glycogen." By D. J. MANNERS and KHIN MAUNG.

5860. "Preparation of some bisaminoaryl sulphones." By M. BALASUBRAMANIAN and V. BALIAH.

5864. "The constituents of natural phenolic resins. Part XXIII. The constitution of sesamolin." By EDWIN HASLAM and ROBERT D. HAWORTH.

5869. "Cyclisation of 3-aroyl-*meso*benzanthrones to 4 : 5-9 : 10-dibenzopyrene-3 : 8-quinone and its derivatives." By ALAN J. BACKHOUSE and WILLIAM BRADLEY.

5871. "Interaction of polynitro-compounds with aromatic hydrocarbons and bases. Part XV. The association constants for the equilibria in the systems : *s*-trinitrobenzene–benzene and chloranil–benzene." By J. M. CORKILL, R. FOSTER, and D. LL. HAMMICK.

5872. "The constitution of homolycorine and lycorenine." By T. KITAGAWA, W. I. TAYLOR, S. UYEO, and H. YAJIMA.

5873. "Conjugated acids from caster oil. Octadeca-9 : 11-dienoic acid and octadec-11-en-9-ynoic acid (ximenynic or santalbic acid)." By JAMES GRIGOR, D. M. MACINNES, JOHN MCLEAN, and (in part) A. J. P. HOGG.

5874. "Galloflavin. Part II." By JAMES GRIMSHAW, ROBERT D. HAWORTH, and (in part) H. K. PINDRED.

5875. "The alkaline fission of 2-aroyloxyethyldimethylsulphonium iodides : The evaluation of Hammett's substituent constants for some *ortho*-substituents." By P. MAMALIS and H. N. RYDON.

5879. "12-Oxygenated pregnane derivatives. Part V. 12β : 21-Diacetoxy-17β-hydroxypregn-4-ene-3 : 20-dione." By (MRS.) W. J. ADAMS, D. N. KIRK, D. K. PATEL, V. PETROW, and (MRS.) I. A. STUART-WEBB.

5881. "The preparation of the mononitrocinnamaldehydes." By W. DAVEY and J. R. GWILT.

5884. "The preparation of 1 : 2 : 3 : 4 : 6 : 7 : 8 : 9-Octahydrodibenzothiophen." By W. COOPER.

5889. "Potential thiophen chemotherapeutics. Part IV. The thiophen analogues of *p*-acetamidobenzaldehyde thiosemicarbazone and sulphanilamide." By J. CYMERMAN-CRAIG and D. WILLIS.

5890. "Acylation and allied reactions catalysed by strong acids. Part XIII. The isomeric *p*-tolyl xylyl sulphones." By H. BURTON and P. F. G. PRAILL.

5891. "*X*-Ray studies in the caryophyllene series. The chloride and bromide from β-caryophyllene alcohol." By J. MONTEATH ROBERTSON and G. TODD.

5892. "Aryl-2-halogenoalkylamines. Part XIII. Chloroethylamino-derivatives of some phenoxyalkanoic acids and of some substituted α-amino-acids." By W. DAVIS, J. J. ROBERTS, and W. C. J. ROSS.

5893. "The synthesis of aromatic aldehydes by means of the dinitrogen tetroxide reagent." By B. O. FIELD and J. GRUNDY.

5894. "Thermodynamic indicator constants of dinitrophenols in dioxan–water mixtures." By S. KERTES.

5896. "Configurational studies in synthetic analgesics." By A. H. BECKETT and A. F. CASY.

5898. "Quinones. Part V. The chemistry of naphthazarin." By D. B. BRUCE and R. H. THOMSON.

5908. "The photolysis of acetaldehyde. Part III. The reaction in the presence of nitric oxide." By V. PRETORIUS, I. H. S. HENDERSON, and C. J. DANBY.

5909. "The preparation and properties of triphenyl borate and the phenoxyboron chlorides." By T. COLCLOUGH, W. GERRARD, and M. F. LAPPERT.

5911. "The formulation of the acidity function J_0." By V. GOLD.

5913. "Purpurogallin. Part XII. The action of organometallic compounds on the tropolones." By E. D. HAWORTH and P. B. TINKER.

5914. "The constitution of conessine. Part VIII. Reaction of cholesteryl toluene-*p*-sulphonate with liquid ammonia." By R. D. HAWORTH, L. H. C. LUNTS, and J. MCKENNA.

5915. "9 : 10-Dihydrophenanthrenes. Part III. Optically active 9 : 10-dihydro-3 : 4-5 : 6-dibenzophenanthrene." By D. MURIEL HALL and E. E. TURNER.

5916. "Oxidation of organic sulphides. Part III. A survey of the autoxidizability of monosulphides." By L. BATEMAN and J. I. CUNNEEN.

5917. "Oxidation of organic sulphides. Part IV. Autoxidation of *cyclo*hex-2-enyl methyl sulphide." By L. BATEMAN and F. W. SHIPLEY.

5919. "Dithiols. Part XV. Some polyhydroxy-derivatives of 3 : 4-dimercaptobutanol." By N. S. JOHARY and L. N. OWEN.

5920. "Dithiols. Part XVI. The *O*-β-D-glucoside of 1 : 3-dimercaptopropan-2-ol." By N. S. JOHARY and L. N. OWEN.

5921. "The preparation of aldotetroses from aldopentoses *via* 1 : 1'-diethylsulphonyl-3 : 4 : 5-trihydroxypent-1-enes." By L. HOUGH and T. J. TAYLOR.

5922. "Surface forces of lecithin sols in the presence of some inorganic salts." By P. H. ELWORTHY and L. SAUNDERS.

5926. "The chemistry of extractives from hardwoods. Part XXII. The structure of diterpenes from *Vouacapoua* species." By F. E. KING, D. H. GODSON, and T. J. KING.

5927. "The characteristic infra-red absorption frequencies of aromatic trifluoromethyl compounds." By R. R. RANDLE and D. H. WHIFFEN.

5930. "Polyazanaphthalenes. Part II. Attempted synthesis of some analogues of pteroic acid." By PHYLLIS D. LANDOR and H. N. RYDON.

5931. "The chemistry of ribose and its derivatives. Part IV. 2 : 3-Di-*O*-methyl-D-ribose." By G. R. BARKER and D. C. C. SMITH.

5932. "The chemistry of ribose and its derivatives. Part V. The synthesis of methyl ethers by partial methylation." By G. R. BARKER, T. M. NOONE, D. C. C. SMITH, and J. W. SPOORS.

5934. "A modified benziminazole synthesis. Part II. A route to unsymmetrically substituted 2 : 2'-dibenziminazolyls and methylenebis-2-benziminazoles." By E. S. LANE.

5935. "Sulphonium compounds related to aryldi-2-halogenoalkylamines." By J. J. ROBERTS and W. C. J. ROSS.

5938. "Cyclic amidines. Part IV. 5 : 6 : 11 : 12-Tetrahydro-5 : 11-*endo*methylenephenhomazine and Tröger's base." By F. C. COOPER and M. W. PARTRIDGE.

5940. "Carcinogenic nitrogen compounds. Part XVII. The synthesis of angular benzacridines." By NG. PH. BUU-HOÏ, RENE ROYER, and MICHEL HUBERT-HABART.

5941. "Synthesis of *S*-(5'-deoxyadenosine-5')-homocysteine, a product from enzymic methylations involving 'active methionine'." By J. BADDILEY and G. A. JAMIESON.

5942. "Anodic syntheses. Part XIII. Chain extension of fatty acids by electrolysis with benzyl half esters." By R. P. LINSTEAD, B. C. L. WEEDON, and B. WLADISLAW.

5945. "Steroids. Part XV. 22 : 23-Dibromo-11-oxoergosta-8 : 14-dien-3β-yl acetate and related compounds." By JAMES GRIGOR, G. T. NEWBOLD, and F. S. SPRING.

5948. "Collision parameters of C_6—C_9 hydrocarbons in the vapour phase : the hydrogen effect." By G. A. MCD. CUMMINGS, E. MCLAUGHLIN, and A. R. UBBELOHDE.

5955. "The constitution of complex metallic salts. Part XV. Palladium derivatives of *o*-dimethylaminophenyldimethylarsine." By FREDERICK G. MANN and FREDERICK H. C. STEWART.

5956. "Simple analogues of cortisone. Part IV. Some benzyl substituted glycolloyl-*cyclo*hexanols." By J. D. BILLIMORIA.

5957. "Cytoactive amino-acids and peptides. Part II. Resolution of *p*-substituted phenylalanines and synthesis of *p*-di-(2-chloroethyl)amino-DL-phenyl[β-^{14}C]alanine." By F. BERGEL, V. C. E. BURNOP, and J. A. STOCK.

5965. "Vapour pressures of some unsaturated hydrocarbons containing six carbon atoms." By G. A. MCD. CUMMINGS and E. MCLAUGHLIN.

5966. "Experiments in the synthesis of santonin. Part IV. The preparation of the lactone of 1 : 2 : 3 : 4 : 7 : 10-hexahydro-1-hydroxy-8 : 10-dimethyl-7-oxo-2-naphthylacetic acid (*nor*santonin) and of 1 : 2 : 3 : 4 : 5 : 6 : 7 : 10-octahydro-1-hydroxy-10-methyl-7-oxo-2-naphthylacetic acid." By F. D. GUNSTONE and A. P. TULLOCH.

5972. "Derivatives of benzo-1 : 4-dioxan. Part III." By P. M. HEERTJES, (MRS.) A. A. NIJMAN-KNAPE, H. TALSMA, and N. J. FAASEN.

5973. "Triterpenoids. Part XXXIV. The constitution of *cyclo*artenol." By D. S. IRVINE, J. A. HENRY, and F. S. SPRING.

5976. "Characterisations of methyl 4 : 6-*O*-benzylidene-α-D-galactoside and of 2 : 3-di-*O*-methyl-D-galactose." By D. J. BELL and G. D. GREVILLE.

5983. "The chemistry of extractives from hardwoods. Part XXIII. The isolation of a new triterpene (terminolic acid) from *Terminalia ivorensis*." By F. E. KING, T. J. KING, and J. M. ROSS.

5989. "The conductivity of silver nitrate in non-aqueous and mixed solvents. Part II." By V. S. GRIFFITHS and K. S. LAWRENCE.

51008. "Steroids. Part X. The preparation of unsaturated steroids." By D. R. JAMES, and R. W. REES, and C. W. SHOPPEE.

ADDITIONS TO THE LIBRARY

I. *Donations*

A. *Books.*

LOVERN, JOHN ARNOLD. The chemistry of lipids of biochemical significance. London 1955. pp. xiii + 132. ill. (Methuen's Monographs on Biochemical Subjects.) 8*s.* 6*d.* (*Recd.* 20/1/55.) From the Publishers: Messrs. Methuen & Co., Ltd.

B. *Pamphlets.*

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH. Selenium. A short review of its production and utilization with reference to the current shortage. By R. AHSTON, E. G. HILL, and D. NEVILLE-JONES. London 1954. pp. iv + 28.

—— *Chemical Research Laboratory.* The national collection of industrial bacteria. Catalogue of strains. London 1954. pp. [iv] + 32.

MEDICAL RESEARCH COUNCIL. Memorandum No. 29. Indices of heat stress. A statistical comparison of effective temperature and an index based on sweat loss. By F. E. SMITH. London 1955. pp. 51. ill.

TEXAS, UNIVERSITY OF. Publication No. 5109. Biochemical Institute Studies IV. Individual metabolic patterns and human disease: an exploratory study utilizing predominantly paper chromatographic methods. Austin 1951. pp. 205. ill.

II. *By purchase*

AMERICAN SOCIETY FOR TESTING MATERIALS. *Committee E-2 on Emission Spectroscopy.* Index to the literature of spectrochemical analysis. Part III, 1946—1950. By B. F. SCRIBNER and W. F. MEGGERS. Philadelphia 1954. pp. iii + 226. (*Reference.*) A.S.T.M. $4.50.

DECHEND, HERTHA VON. Justus von Liebig in eigenen Zeugnissen und solchen seiner Zeitgenossen. Weinheim 1953. pp. 141. ill. Verlag Chemie. *DM* 8.40. (*Recd.* 18/1/55.)

DOLE, MALCOLM. Introduction to statistical thermodynamics. New York 1954. pp. xii + 250. ill. Prentice-Hall. $8.33. (*Recd.* 10/1/55.)

HOPFF, HEINRICH, MULLER, ALFRED, and WENGER, FRIEDRICH. Die Polyamide. Berlin 1954. pp. xii + 423. ill. Springer. *DM* 43.20. (*Recd.* 29/12/54.)

REINER, M., and WARD, A. G. *Editors.* Building materials; their elasticity and inelasticity. Amsterdam 1954. pp. xv + 560. ill. (Deformation and Flow.) North-Holland Pub. Co. 84*s.* (*Recd.* 29/12/54.)

TURBA, FRITZ. Chromatographische Methoden in der Protein-Chemie; einschliesslich verwandter Methoden wie Gegenstromverteilung, Papier-Ionophorese. Berlin 1954. pp. viii + 358. ill. Springer. *DM* 69. (*Recd.* 31/12/54.)

LOCAL REPRESENTATIVES OF THE CHEMICAL SOCIETY

Aberdeen.	R. H. Thomson, Ph.D., F.R.I.C., Chemistry Department, The University, Old Aberdeen.
Australia.	Professor A. J. Birch, M.Sc., D.Phil., Department of Organic Chemistry, The University, Sydney, N.S.W., Australia.
Birmingham.	J. C. Tatlow, B.Sc., Ph.D., Department of Chemistry, The University, Edgbaston, Birmingham, 15.
Bristol.	P. Woodward, B.Sc., Ph.D., Chemistry Department, The University, Woodland Road, Bristol.
Cambridge.	R. N. Haszeldine, B.Sc., M.A., Ph.D., University Chemical Laboratory, Pembroke Street, Cambridge.
Canada.	W. D. McFarlane, M.A., Ph.D., The Laboratories, The Canadian Breweries Ltd., 496, Queen Street East, Toronto, 2, Canada.
Ceylon.	M. U. S. Sultanbawa, B.Sc., Ph.D., A.R.I.C., Department of Chemistry, The University, Colombo, Ceylon.
Edinburgh.	T. R. Bolam, D.Sc., Chemistry Department, King's Buildings, West Mains Road, Edinburgh.
Exeter.	K. Schofield, B.Sc., Ph.D., Department of Chemistry, Washington Singer Laboratories, Prince of Wales' Road, Exeter.
Glasgow.	D. S. Payne, B.Sc., Ph.D., A.R.I.C., Chemistry Department, The University, Glasgow, W.2.
Hull.	G. W. Gray, B.Sc., Ph.D., Chemistry Department, The University, Hull.
India.	Professor T. R. Seshadri, M.A., Ph.D., F.R.I.C., Department of Chemistry, The University, Delhi, India.
Irish Republic.	D. O Tuama, M.Sc., Ph.D., F.I.C.I., Medical Research Council of Ireland, The Laboratories, Trinity College, Dublin.
Leeds.	E. Rothstein, Ph.D., D.Sc., A.R.C.S., Organic Chemistry Department, The University, Leeds, 2.
Liverpool.	A. K. Holliday, B.Sc., Ph.D., Department of Physical and Inorganic Chemistry, The University, Liverpool.
,,	D. W. Broad, Ph.D., A.R.I.C., Imperial Chemical Industries, Ltd., Research Department, Widnes Laboratory, Widnes.
Manchester.	G. R. Barker, B.Sc., Ph.D., Chemistry Department, The University, Manchester, 13.
,,	M. A. T. Rogers, B.Sc., Ph.D., A.R.I.C., Imperial Chemical Industries, Ltd., Hexagon House, Blackley, Manchester.
Newcastle and Durham.	G. A. Swan, D.Sc., Ph.D., F.R.I.C., Department of Chemistry, King's College, Newcastle-on-Tyne, 1.
New Zealand.	Professor S. N. Slater, M.Sc., D.Phil., A.R.I.C., Chemistry Department, Victoria University College, Wellington, New Zealand.
Northern Ireland.	R. G. R. Bacon, Ph.D., A.R.C.S., Chemistry Department, Queen's University, Belfast.
North Wales.	J. E. McKail, Ph.D., Department of Chemistry, University College of North Wales, Bangor.
Nottingham.	C. C. Addison, D.Sc., Ph.D., F.R.I.C., Chemistry Department, The University, University Park, Nottingham.
Oxford.	L. A. K. Staveley, M.A., Inorganic Chemistry Laboratory, South Parks Road, Oxford.
Pakistan.	M. I. D. Chughtai, M.Sc.Tech., Ph.D., A.R.I.C., Punjab University Institute of Chemistry, The Mall, Lahore, Pakistan.
St. Andrews and Dundee.	C. Horrex, M.A., Ph.D., Chemistry Department, The University, St. Andrews.
Sheffield.	H. J. V. Tyrrell, M.A., B.Sc., Chemistry Department, The University, Sheffield, 10.
South Africa.	Professor W. Pugh, Ph.D., B.Sc., F.R.I.C., Chemistry Department, University of Cape Town, Rondebosch, S. Africa.
Southampton.	N. B. Chapman, M.A., Ph.D., Department of Chemistry, The University, Southampton.
South Wales.	K. W. Sykes, M.A., B.Sc., D.Phil., Department of Chemistry, University College, Singleton Park, Swansea.

PROCEEDINGS

OF THE

CHEMICAL SOCIETY

SCIENTIFIC MEETINGS DURING MAY, 1955

LONDON.

Thursday, May 5th, **1955,** at 7.30 *p.m.*

The following papers will be read and discussed :

" Polynucleotide Synthesis. Dithymidine 3' : 5'-dinucleotide." By A. M. Michelson and Sir Alexander R. Todd.

" The Chemistry of Fungi. Part XXVI. Rosonolactone." By A. Harris, A. Robertson, and W. B. Whalley.

" The Red Colour given by Coal-tar Phenols and Aqueous Alkalis. Isolation of a Quinone derived from a Tetrahydroxytetramethyldiphenyl." By W. Baker and D. Miles.

To be held in the Rooms of the Society, Burlington House, W.1.

Abstracts of the Papers for discussion may be obtained from the General Secretary.

EXETER.

Thursday, May 6th, **1955,** at 5.0 *p.m.*

Lecture, **Acetylene-Allene Chemistry,** by Professor E. R. H. Jones, Ph.D., D.Sc., F.R.I.C., F.R.S. To be given in the Washington Singer Laboratories.

IRISH REPUBLIC.

Monday, May 2nd, **1955,** *at* 7.45 *p.m.*

Lecture, **The Nature of Adsorption Forces,** by Professor H. C. de Boer. Joint meeting with the Institute of Chemistry of Ireland, the Royal Institute of Chemistry, the Society of Chemical Industry, and University College, Dublin. To be held in the Chemistry Department, University College, Dublin.

Tuesday, May 3rd, at 7.45 *p.m.*

Lecture, **The Fundamental Principles of Catalysts,** by Professor H. C. de Boer. Joint meeting with the Institute of Chemistry of Ireland, the Royal Institute of Chemistry, the Society of Chemical Industry, and University College, Dublin. To be held in the Chemistry Department, University College, Dublin.

Friday, May 6th, at 7.45 *p.m.*

Lecture, **The Fundamental Principles of Catalysts,** by Professor H. C. de Boer. Joint meeting with the Institute of Chemistry of Ireland, the Royal Institute of Chemistry, and the Society of Chemical Industry. To be held in the Chemistry Department, University College, Cork.

Monday, May 9th, at 7.45 p.m.

Lecture, **The Fundamental Principles of Catalysts,** by Professor H. C. de Boer. Joint meeting with the Institute of Chemistry of Ireland, the Royal Institute of Chemistry, and the Society of Chemical Industry. To be held in the Chemistry Department, University College, Galway.

Friday, May 20th, at 7.45 p.m.

Lecture, **Some Applications of Flash Photolysis,** by Professor R. G. W. Norrish, Sc.D., F.R.I.C., F.R.S. Joint meeting with the Werner Society, to be held in the Chemistry Department, Trinity College, Dublin.

LEEDS.

Wednesday, May 18th, 1955, at 10.0 a.m.

Official Meeting and Symposium, **The Friedel–Crafts Reaction.** Speakers will include Professor W. Bradley, Professor H. C. Brown, Dr. E. Rothstein, Professor A. G. Evans, Dr. G. Baddeley, Professor D. D. Eley, Dr. F. Fairbrother, Dr. R. O. Colclough, Dr. D. C. Pepper, Dr. P. H. Plesch. To be held in Chemistry Lecture Theatre, The University.

Thursday, May 19th, at 6.30 p.m.

Centenary Lecture, **Chemical Effects of Steric Strains,** by Professor H. C. Brown, Ph.D. To be given in the Chemistry Lecture Theatre, The University.

MANCHESTER.

Thursday, May 26th, 1955, at 6.30 p.m.

Centenary Lecture, **Chemical Effects of Steric Strains,** by Professor H. C. Brown, Ph.D. To be given in the Chemistry Lecture Theatre, The University.

NEWCASTLE AND DURHAM.

Friday, May 13th, 1955, at 5.30 p.m.

Centenary Lecture, **Chemical Effects of Steric Strains,** by Professor H. C. Brown, Ph.D. To be given in the Chemistry Building, King's College, Newcastle-on-Tyne.

SHEFFIELD.

Monday, May 23rd, 1955, at 7.30 p.m.

Centenary Lecture, **Chemical Effects of Steric Strains,** by Professor H. C. Brown, Ph.D. Joint meeting with Sheffield University Chemical Society. To be held in the Chemistry Lecture Theatre, The University.

SOUTHAMPTON.

Friday, May 6th, 1955, at 5.0 p.m.

Lecture, **Kinetics of Some Organic Reactions,** by Mr. R. P. Bell, M.A., F.R.S. Joint meeting with Southampton University Chemical Society. To be held in the Chemistry Department, The University.

OFFICIAL ANNOUNCEMENTS

DEATHS.

The Council regrets to announce the deaths of the following Fellows:

	Elected.	Died.
John Stanley Herbert Davies (Wilmslow)	Jan. 18th, 1945.	July 26th, 1954.
Harold Bertram Holthouse (Nottingham)	Dec. 17th, 1893.	Jan. 28th, 1955.
Gerhard Wilhelm Frederic Kroll (Bangor)	June 3rd, 1954.	Dec. 21st, 1954.
Frank Harold Lowe (Claygate)	June 15th, 1904.	Jan. 21st, 1955.
David Baird Macdonald (Narborough)	Dec. 3rd, 1903.	Dec. 19th, 1954.
Leonard William Ragg (Long Melford)	Aug. 7th, 1941.	Dec. 12th, 1954.

CONGRATULATIONS.

The President has conveyed the congratulations of the Society to the following Fellows who completed 60 years of Fellowship on February 21st, 1955:

Francis Howard Carr (Petersfield).
Arthur Marshall (London, W. 8).
Thomas Cotterill Warrington (Marple).

and to the following Fellows who completed 50 years of Fellowship on February 15th, 1955:

Friend Ebenezer Clark (W. Virginia).
Bernard Collitt (Montreal).
Frederick William Heely (Alford).
Ernest Quant (Torquay).
William Herbert Simmons (London, W.1).

ELECTION OF NEW FELLOWS.

The following 113 candidates were elected Fellows of the Society on February 17th, 1955:

Marjorie Mary Aitken.
Peter Cyril James Allman.
Laurence Edward Anderson.
Jack Asquith.
Donald E. Ayer.
Alfred Frances Hayes Baker.
Robert Andrew Bauman.
Michael Hewitt Benn.
John Ruskin Bennett.
Arieh Berger.
Jan Antoni Bieganski.
Edward Edmond Boake.
Nevison George Boast.
Peter Briess.
Luther C. Browning.
George Herbert Bull.
Peter Irlam Burkhill.
Charles Frederick Cardy.
Gaetano Caronna.
Thomas Ronald Carrington.
John Carruthers.
Alan Ryton Caverhill.
Stanley William Caywood.
Earl C. Chapin.
Dennis Chapman.
Mendel David Cohen.
Michael John Collis.
Michael Victor Cooksley.
Peter Jackson Coope.
William Addison Cramp.
Stanley James Cressey.
John Robert Crowder.
Jatashanker Sadashiv Dave.
Norman Alexander Dobson.
L. Guy Donaruma.
Raymond John Downing.
Raymond John Jewell Egenes.
Keith Ellis.
Silvio Arthur Fallab.
William Ray Feldman.
Ronald Field.
Michael Anthony Foster.
Richard E. Glick.
Michael A. Greenbaum.
Peter John Haines.
Ronald Walter Hall.
Jack Halpern.
Terrence Jack Harper.
David Edward Hayler.
Alan Charles Hazell.
Sheila Hollingshead.
John James Holt.
Jonathan Humphreys.
Mark Hely Hutchinson.
Abdel Hamid Ibrahim.
Colin Taylor Ironside.
James Keith Jacques.
Patrick Aloysius Kearney.
Kenneth David Kopple.
Anthony David Leach.

John Bryant Leane.
Warren Albert Ledger.
David Stuart Letham.
John Samuel Littler.
Samuel James Lyle.
Peter McConnell.
Norman James McCorkindale.
William Desmond McGrath.
David Andrew Mathewes.
George Lionel Mattok.
Yehuda Mazur.
George Stewart Mill.
Ronald George Samuel Morfee.
David William Newill.
Ian Ritchie Nightingale.
Robert Edwin Oakey.
E. Paszthory.
Robert Carlyle Petterson.
Robert E. Plapinger.
John William Powell.
Peter John Mayhew Radford.
Michael Samuel Redstone.
Robert William Reid.
David Arthur Edgar Rendell.
Michael Roe.
Phyllis Mary Sanderson.
Graham Saville.
Franco Scardiglia.
Jack William Arthur Seaman.
Alwyn Senior.
Peter Roy Sewell.
Clifford H. Shunk.
George Harold Singer.
John David Smith.
Douglas Lintin Swallow.
John Watson Taylor.
Victor H. Tiensuu.
Robert Charles Noel Tinsley.
Michael James Lever Tillotson.
Archibald Toppin.
Lin Tsai.
Adambhai Ahmedbhai Vahora.
Dirk Willem Van Krevelen.
Lance Strother Walters.
Charles Kenneth Warren.
Frederick William Wassmundt.
John George Watkinson.
Anthony Michael Spicer White.
Denis White.
David Lanceley Wigley.
Geoffrey Arthur Wood.
David Buchanan Wootton.
Mohd Zafarullah.

CORDAY-MORGAN MEDAL AND PRIZE.

The Corday–Morgan Medal and Prize for **1953** has been awarded to Dr. John Warcup Cornforth.

The Corday–Morgan Medal and Prize, consisting of a Silver Medal and a monetary Prize of 150 Guineas, is awarded annually to the chemist of either sex and of British Nationality, who, in the judgment of the Council of the Chemical Society, shall have published during the year in question the most meritorious contribution to experimental chemistry, and who shall not, at the date of publication, have attained the age of thirty-six years. The Council has power to suspend the award in any year in which no suitable candidate presents himself or is brought to the notice of the Council.

Copies of the rules governing the award may be obtained from the General Secretary. Applications or recommendations in respect of the award for the year **1954** must be received not later than **December 31st, 1955,** and applications for the award for **1955** are due before the end of **1956.**

LIBRARY.

The Library will close for the Easter Holiday at 1 p.m. on Thursday, April 7th, and re-open at 10 a.m. on Wednesday, April 13th, 1955.

INFRA-RED SPECTRA ACCEPTED FOR DEPOSITION.

Details of infra-red spectra, C.S. Nos. 1—140, accepted for deposition with the Society, are given in the **1954** *Journal* Index Issue, pp. **4770—4773.**

QUARTERLY REVIEWS.

Quarterly Reviews, Vol. IX, No. 1, will contain the following articles :

" The electromagnetic separation of stable isotopes," by R. H. V. M. Dawton and Mervyn L. Smith.
" The application of mass spectrometry to chemical problems," by W. J. Dunning.
" The principles of hydrogen-isotope exchange reactions in solution," by V. Gold and D. P. N. Satchell.
" The enzymic degradation of polysaccharides," by D. J. Manners.

It is expected that forthcoming issues will include the following articles.

" Boron hydride chemistry," by F. G. A. Stone.
" The chemistry of the NO group," by C. C. Addison and J. Lewis.
" Alkyl–oxygen heterolysis in carboxylic esters and related compounds," by A. G. Davies and J. Kenyon.
" The chemistry of 5-oxazolones," by E. Baltazzi.

INTERNATIONAL CONGRESS ON DOCUMENTATION OF APPLIED CHEMISTRY.

The First International Congress on Documentation of Applied Chemistry will be held in London from November 23rd to 25th, 1955. The registration of members attending will take place on the evening of Tuesday, November 22nd.

The Congress, held under the patronage of the International Union of Pure and Applied Chemistry, is sponsored by the Society of Chemical Industry, and has as President of Honour the Rt. Hon. Lord Cherwell, C.H., F.R.S. The Chairman of Council is Sir William Ogg, M.A., Ph.D., LL.D., Director of Rothamsted Experimental Station.

An Organizing Committee has been set up with Dr. Leslie H. Lampitt as Chairman and Dr. Alexander King as Deputy Chairman. Dr. D. W. Kent-Jones is Honorary Treasurer and Lt.-Col. Francis J. Griffin is Honorary Secretary.

Membership of the Congress is open to all interested persons on payment of the membership fee of £2 2*s*. It is hoped to issue the detailed programme in the near future and all enquiries should be addressed to the Honorary Secretary, International Congress on Documentation of Applied Chemistry, 56 Victoria Street, London, S.W.1.

MINUTES OF SCIENTIFIC MEETINGS

Minutes of a

SCIENTIFIC MEETING

held at Burlington House, on Thursday, February 3rd, 1955, at 7.30 p.m.

The President, PROFESSOR W. WARDLAW, C.B.E., D.Sc., F.R.I.C., was in the Chair.

MINUTES.

The Minutes of the Scientific Meeting held in the Large Chemistry Lecture Theatre, Imperial College of Science and Technology, South Kensington, London, S.W.7, held on January 20th, 1955, were read, and were confirmed and signed.

FORMAL ADMISSION OF FELLOWS.

The following were admitted Fellows of the Society: C. Gardner Swain, Geoffrey R. Ames, Douglas C. Eagles.

SCIENTIFIC COMMUNICATIONS.

The following papers were read and discussed:

" Oenanthotoxin and Cicutoxin. Part II. Synthetical Experiments." By (Miss) B. E. Hill, B. Lythgoe, S. Mirvish, and S. Trippett.
" Researches on Polyenes. Part III. The Synthesis and Light Absorption Properties of the Dimethylpolyenes." By P. Nayler and M. C. Whiting.
" Anodic Synthesis. Part XIV. The Use of Acetylenic Components. A New Synthesis of Oleic Acid." By B. W. Baker, R. P. Linstead, and B. C. L. Weedon. (Read by Dr. L. Crombie.)

Minutes of a

SCIENTIFIC MEETING

held in the Chemistry Department, The University, Birmingham, on Friday, February 4th, 1955, at 4.30 p.m.

PROFESSOR M. STACEY, D.Sc., F.R.S., welcomed the Society to Birmingham, and the President, PROFESSOR W. WARDLAW, C.B.E., D.Sc., F.R.I.C., who was in the Chair, replied on behalf of the Society.

FORMAL ADMISSION OF FELLOWS.

The following were admitted Fellows of the Society: G. Vaughan, S. A. Barker, G. A. Gilbert, J. E. Fildes, G. Riley, R. Woodgar, D. Horton, A. Fairhurst, M. Kapel, John M. Thompson, R. A. Cox, A. Sykes, R. L. Vale, W. G. P. Robertson.

LECTURE.

The President called upon Professor R. G. W. Norrish, Sc.D., F.R.S., to deliver a Lecture entitled "The Photochemistry of Poly(methyl Vinyl Ketone)." At the conclusion of the lecture, a vote of thanks to Professor Norrish, proposed by Dr. J. C. Robb, was carried with acclamation.

Minutes of a

SCIENTIFIC MEETING

held at Burlington House, on Thursday, February 17th, 1955, at 7.30 p.m.

The President, PROFESSOR W. WARDLAW, C.B.E., D.Sc., F.R.I.C., was in the Chair.

MINUTES.

The Minutes of the Scientific Meetings held at Burlington House and at the University of Birmingham, on February 3rd and 4th, respectively, were read, and were confirmed and signed.

VACANCIES ON COUNCIL 1955-56.

The list of nominations was read.

APPOINTMENT OF SCRUTATORS.

Dr. A. G. Davies and Dr. Bryce Smith were appointed scrutators for the ballot for the election of Vice-Presidents and Ordinary Members of Council.

FORMAL ADMISSION OF FELLOWS.

The following were admitted Fellows of the Society: S. Galandauer, D. Pedder, A. Richmond, K. R. Jennings, S. Smith, N. R. Davies, A. Blackburn.

SCIENTIFIC COMMUNICATIONS.

The following papers were read and discussed:

"Binding in some Diatomic Molecules." By J. W. Linnett.

"The Pyrolysis of Organomercury Compounds." By H. V. Carter, E. I. Chappell, and E. Warhurst.

"The use of Equilibrium Constants to Calculate Thermodynamic Quantities. Part II." By K. E. Howlett.

Minutes of a

SCIENTIFIC MEETING

held in the University Chemical Laboratory, Pembroke Street, Cambridge, on February 18th, 1955, at 8.30 p.m.

The President, PROFESSOR W. WARDLAW, C.B.E., D.Sc., F.R.I.C., was in the Chair, and replied to Sir Alexander Todd, who welcomed the Society to Cambridge.

FORMAL ADMISSION OF FELLOWS.

The following were admitted Fellows of the Society: F. G. Mann, E. A. Moelwyn Hughes, P. G. Ashmore, H. Gutfreund, Michael H. Searby, B. A. Thrush, B. Cox, N. Sheppard, R. J. Marklow, S. A. Faseeh, R. Ingleby, Michael Taylor, I. G. Hinton, W. C. Ahlers, M. Onyszchuk, J. P. Simons, J. H. Isaacson, C. J. Willis, K. W. Humphreys, Frank W. Brown, D. Harrison, J. C. R. Turner.

LECTURE.

The President called upon Mr. R. P. Bell, M.A., F.R.S., to deliver a lecture entitled, "The Physical Chemistry of Acetaldehyde Solutions." At the conclusion of the Lecture, a vote of thanks to Mr. Bell, proposed by Dr. P. G. Ashmore, was carried with acclamation.

PAPERS ACCEPTED

(List of Papers accepted between January 25th and February 22nd, 1955, for publication in the *Journal*.)

Numbers quoted are "Reprint Order Numbers." Reprints may be ordered from the list below, or from the published *Journal* (January 1954 onwards). Orders must be sent to the General Secretary accompanied by a remittance for 5*s*. for each reprint or by the appropriate number of reprint vouchers. Reprint voucher books may be obtained price 10*s*. per book of five vouchers, available to Fellows and to those who subscribe to the *Journal*. Fellows, but not subscribers, may also obtain books, limited to one per Fellow, containing 30 reprint vouchers at £1 10*s*. per book.

5569. "Compounds of tertiary amines with nitrosyl chloride and with dinitrogen tetroxide." By A. E. COMYNS.

5757. "The orientation of disubstituted fluoranthene derivatives." By NEIL CAMPBELL and N. H. KEIR.

5812. "Dissociation constants of the dihydrolysergic acids." By J. B. STENLAKE.

5848. "Synthesis of 2 : 3–6 : 7-dibenzofluoranthene." By NEIL CAMPBELL, ANGUS MARKS, and G. V. MCHATTIE.

5862. "Kinetic studies of the oxidation of aromatic compounds by potassium permanganate. Part II. Substituted toluenes." By C. F. CULLIS and J. W. LADBURY.

5867. "The thermal and photochemical decomposition of triphenylhydrazine." By P. F. HOLT and B. P. HUGHES.

5868. "The kinetics of anodic processes at very low current density. Part I. The anodic dissolution of copper and mercury." By S. E. S. EL WAKKAD, T. M. SALEM, and S. E. KHALAFALLA.

5876. "Tracer studies on ester hydrolysis. Part I. Triphenylmethyl acetate." By C. A. BUNTON and (MRS.) ALICJA KONASIEWICZ.

5877. "Molecular polarisability. The electro-optical polarisability tensor, ellipsoids of naphthalene, and the α- and β-fluoro-, -chloro-, -bromo- and -iodo-naphthalenes." By (MRS.) C. G. LE FÈVRE and R. J. W. LE FÈVRE.

5878. "Mesomorphism and chemical constitution. Part V. The mesomorphic properties of the 4′-*n*-alkoxydiphenyl-4-carboxylic esters and their simple alkyl esters." By G. W. Gray, J. B. Hartley, and Brynmor Jones.

5883. "The preparation and properties of some dipyrazolyls." By I. L. Finar.

5885. "The degradation of carbohydrates by alkali. Part IX. Cellobiose, cellobiulose, celliotetraose, and laminarin." By W. M. Corbett and J. Kenner.

5886. "Thermodynamics of ion association. Part I. Lead chloride, bromide, and nitrate." By G. H. Nancollas.

5900. "Calculated bond lengths in some cyclic compounds. Part I. Methods of calculation." By T. H. Goodwin and V. Vand.

5901. "Calculated bond lengths in some cyclic compounds. Part II. Benzanthrone, acedianthrone, and flavanthrone." By T. H. Goodwin.

5903. "The capacity of the double layer at a mercury anode." By S. E. S. El Wakkad and T. M. Salem.

5904. "Heterocyclic fluorine compounds. Part II. *Bz*-Monofluoroindoles." By F. L. Allen, J. C. Brunton, and H. Suschitzky.

5905. "Adsorption on charcoal from aqueous solutions of fatty acids; a further interpretation of Traube's rule." By A. Blackburn and J. J. Kipling.

5907. "The effect of structure upon polarographic behaviour. Part I. The depolarisation potentials of Girard-T compounds." By J. R. Young.

5910. "The reactions of highly fluorinated organic compounds. Part VIII. The gas-chromatographic separation on a preparative scale and some reactions of 3*H*- and 4*H*-nonafluoro*cyclo*hexene." By D. E. M. Evans and J. C. Tatlow.

5925. "A general treatment of the solvent extraction of inorganic compounds." By H. Irving, F. J. C. Rossotti, and R. J. P. Williams.

5928. "Pteridine derivatives. Part I. A new synthesis of 2-amino-4-hydroxypteridines." By G. P. G. Dick and H. C. S. Wood.

5936. "The oxidation of hydrazine in aqueous solution. Part III. Some aspects of the kinetics of oxidation of hydrazine by iron(III) in acid solution." By W. C. E. Higginson and P. Wright.

5943. "The purification of germanium. The germanium tetrachloride–arsenic trichloride system." By Mino Green and James A. Kafalas.

5944. "Organosilicon compounds. Part XII. Substituted 9-fluorenyltrimethylsilanes." By C. Eaborn and R. A. Shaw.

5949. "Polymerisation of thiophen derivatives. Part IV. The formation of some 9-thia-1 : 2- and 9-thia-3 : 4-benzofluorene derivatives." By W. Davies, F. C. James, S. Middleton, and Q. N. Porter.

5950. "Tracer studies on ester hydrolysis. Part II. The acid hydrolysis of *tert.*-butyl acetate." By C. A. Bunton and J. L. Wood.

5952. "2-Alkylthio-4 : 5-dihydroglyoxalinium salts." By Walter Wilson.

5953. "Homolytic aromatic substitution. Part IX. Competitive experiments on the arylation of chlorobenzene and nitrobenzene with *p*-chlorophenyl radicals." By J. I. G. Cadogan, D. H. Hey, and Gareth H. Williams.

5958. "The benzoin reaction with terephthalaldehyde." By J. Idris Jones and P. B. Tinker.

5959. "The kinetics of the reduction of azoxybenzene (and some derivatives) by titanous chloride." By M. J. Stephen and Sir Cyril Hinshelwood.

5962. "Demonstration of bimolecular substitution with anionotropic rearrangement (S_N2') in 1-methylallyl bromide." By B. D. England.

5963. "Methyl affinities of aromatic compounds." By C. A. Coulson.

5970. "The oxidation of olefins with perbenzoic acids. A kinetic study." By B. M. Lynch and K. H. Pausacker.

5974. "Reactions of unsaturated compounds. Part XII. The course of oxidation of olefins by chromic acid." By W. J. Hickinbottom, D. Peters, and (in part) D. G. M. Wood.

5975. "Reaction of 1 : 2 : 3 : 6-tetrahydrobenzaldehyde with alkali." By E. G. E. HAWKINS, D. J. G. LONG, and F. W. MAJOR.

5977. "The sorption of water vapour by active carbons." By M. M. DUBININ, K. D. ZAVERINA, and V. V. SERPINSKY.

5978. "*NN'*-Diarylthioureas and related compounds of biological interest." By NG. PH. BUU-HOÏ, NG. D. XUONG, and NG. H. NAM.

5979. "Dithiols. Part XVII. *S*-Benzyl derivatives of 2 : 3-dimercaptopropanol and 1 : 3-dimercaptopropan-2-ol." By N. S. JOHARY and L. N. OWEN.

5980. "Dithiols. Part XVIII. Some water-soluble derivatives containing the sulphonic acid group." By N. S. JOHARY and L. N. OWEN.

5982. "Orientation effects in the diphenyl series. Part XIV. The thermal decomposition of some 'diazoperbromides'." By SHIU MAY LOH and E. E. TURNER.

5984. "The kinetics of the oxidation of sulphur dioxide by nitrous oxide." By T. N. BELL, P. L. ROBINSON, and A. B. TRENWITH.

5985. "Some derivatives of diphenylamine." By S. G. P. PLANT and C. R. WORTHING.

5986. "Photobromination studies. Part II. A convenient synthesis of *m*-hydroxybenzaldehyde." By ERNEST L. ELIEL and KENNETH W. NELSON.

5987. "*Acacia karoo* gum." By A. J. CHARLSON, J. R. NUNN, and A. M. STEPHEN.

5990. "The extraction of ferric chloride into non-aqueous solvents." By D. E. CHALKLEY and R. J. P. WILLIAMS.

5992. "Thiophen derivatives of biological interest. Part X. 5-Substituted 2-thenaldehydes and derivatives." By NG. PH. BUU-HOÏ, DENISE LAVIT, and NG. D. XUONG.

5993. "Photo- and semi-conductance of organic crystals. Part I. Photo-effects in tetracene and anthracene." By A. BREE, D. J. CARSWELL, and L. E. LYONS.

5994. "Photo- and semi-conductance of organic crystals. Part II. Spectral dependence, quantum efficiency, and a relation between semi- and photo-effects in anthracene." By D. J. CARSWELL and L. E. LYONS.

51000. "Steroids. Part IX. The catalytic hydrogenation of 3α-substituted Δ^5-steroids." By J. R. LEWIS and C. W. SHOPPEE.

51001. "Steroids and Walden inversion. Part XXIV. The methylation of 3-hydroxysteroids." By J. R. LEWIS and C. W. SHOPPEE.

51002. "Studies in the chemistry of quadrivalent germanium. Part II. The depolymerisation of the pentagermanate ion with change of pH and ion-exchange studies of germanate solutions containing sulphate and orthophosphate." By D. A. EVEREST and J. E. SALMON.

51003. "The extraction of the indium halides into organic solvents." By H. IRVING and F. J. C. ROSSOTTI.

51004. "Researches on acetylenic compounds. Part XLIX. The preparation and ultraviolet absorption spectra of the stereoisomeric conjugated hexadienoic and hexenynoic acids." By J. L. H. ALLAN, E. R. H. JONES, and M. C. WHITING.

51005. "Researches on acetylenic compounds. Part L. The infrared absorption of some conjugated ethylenic and acetylenic systems." By J. L. H. ALLAN, G. D. MEAKINS, and M. C. WHITING.

51006. "The chemistry of extractives from hardwoods. Part XXIV. A saponin constituent of makoré (*Mimusops heckelii*)." By F. E. KING, J. A. BAKER, and T. J. KING.

51010. "Experiments on halogenated ketones. The conversion of 1-bromo-1 : 3-diphenylpropan-2-one into 1-phenylindan-2-one." By A. C. B. SMITH and WALTER WILSON.

6001. "Cyanamides. Part VIII. The interaction of 1-arylbiurets and arenesulphonyl chlorides." By FREDERICK KURZER and J. ROY POWELL.

6006. "The kinetics and mechanism of the reaction of potassium ferrocyanide and nitrosobenzene catalysed by mercuric and mercurous ions and organic mercuric compounds." By S. AŠPERGER and D. PAVLOVIĆ.

6007. " An *X*-ray examination of long-chain alkyl dihydrogen phosphates and dialkyl hydrogen phosphates and their sodium salts." By D. A. Brown, T. Malkin, and G. K. Maliphant.

6008. " ' Diazoperbromides.' " By M. Aroney and R. J. W. Le Fèvre.

6010. " An electromagnetic sorption balance." By S. J. Gregg.

6018. " Configuration of (+)-γ-aminovaleric acid. Conversion of L-alanine into its vinylogue." By K. Balenović and D. Cerar.

6019. " Some α-methylamino-acids." By K. T. Potts.

6020. " Survey of anthoxanthins. Part IX. Isolation and constitution of palasitrin." By (Miss) B. Puri and T. R. Seshadri.

6021. " Reactions of organic azides. Part IV. The conversion of 9-alkylfluoren-9-ols into 9-alkylphenanthridines." By C. L. Arcus and E. A. Lucken.

6022. " Ultraviolet absorption spectra of some mercury compounds." By B. G. Gowenlock and J. Trotman.

6026. " The polarized spectrum of anthracene. Part II. Weak transitions and second-order crystal field perturbations." By D. P. Craig.

6027. " The polarized spectrum of anthracene. Part III. The system at 3800 Å." By D. P. Craig and P. C. Hobbins.

6030. " Chemistry of pongamol. Part III. Synthesis." By S. K. Mukerjee and T. R. Seshadri.

6038. " Purines, pyrimidines, and glyoxalines. Part I. New syntheses of glyoxalines and pyrimidines." By G. Shaw.

6042. " The chemistry of the pyrrocolines. Part VII. Alkyl derivatives." By D. O. Holland and J. H. C. Nayler.

6043. " The chemistry of the pyrrocolines. Part VIII. Further experiments with 2-methylpyrrocoline." By D. O. Holland and J. H. C. Nayler.

6044. " Stereochemical studies of olefinic compounds. Part IV. The configuration of ' leaf alcohol ' and a further synthesis of *cis*-jasmone." By Stanley H. Harper and Raymond J. D. Smith.

6045. " The action of Grignard reagents on anhydro-sugars of ethylene oxide type. Part IV. The behaviour of methyl 2 : 3-anhydro-4 : 6-*O*-benzylidene-α-D-mannoside towards diphenylmagnesium." By G. N. Richards.

6046. " Immunopolysaccharides. Part III. The dimethyl ethers of L-rhamnopyranose." By K. Butler, P. F. Lloyd, and M. Stacey.

6047. " Immunopolysaccharides. Part IV. Structural studies on the type II pneumococcus specific polysaccharide." By K. Butler and M. Stacey.

6048. " A new route to *N*-substituted *o*-phenylenediamines." By E. S. Lane and C. Williams.

6051. " Deoxy-sugars. Part XXVIII. The stability of some substituted glycosylamines in aqueous and non-aqueous solvents." By J. L. Barclay, A. B. Foster, and W. G. Overend.

6060. " The decomposition of cystine in acid solution in the presence of indoles." By J. T. Edward and E. F. Martlew.

6065. " Interaction of boron trichloride with chloro-alcohols and with cyclic ethers." By J. D. Edwards, W. Gerrard, and M. F. Lappert.

6071. " The degradation of carbohydrates by alkali. Part X. Acetalic derivatives." By W. M. Corbett, J. Kenner, and G. N. Richards.

ADDITIONS TO THE LIBRARY

I. *Donations*

A. *Books.*

FRY, B. A. The nitrogen metabolism of micro-organisms. London **1955**. pp. ix + 166. ill. (Methuen's Monographs on Biochemical Subjects.) **9s. 6d.** (*Recd.* **17/2/55.**)
From the Publishers: Messrs. Methuen & Co., Ltd.

B. *Pamphlets.*

BRUGMAN, FREDERIK WILHELM. De additie van formaldehyde aan enige α,β-alkeen-monocarbonzuren. [Djakarta **1954.**] pp. [iv] + **56.**

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH. Methods for the detection of toxic gases in industry. Leaflet No. 10. Chlorine (revised edition). London **1955.** pp. [iv] + **6.** ill.

ROYAL INSTITUTE OF CHEMISTRY. Lectures, Monographs and Reports, **1955.** No. **1.** Ionisation in organic chemistry. By EDWARD DAVID HUGHES. [London **1955.**] pp. [ii] + **24.** [Two copies.]

II. *By purchase*

ADIROWITSCH, E. I. Einige Fragen zur Theorie der Lumineszenz der Kristalle. Berlin **1953.** pp. xii + **298.** ill. Akademie-Verlag. *DM* **19.** (*Recd.* **1/2/55.**)

BATES, ROGER G. Electrometric pH determinations. Theory and practice. New York **1954.** pp. xiii + **329.** ill. Wiley. **$7.50.** (*Recd.* **22/2/55.**)

BLOM, A. V. Grundlagen der Anstrichwissenschaft. Basel **1954.** pp. **385.** ill. Verlag Birkhäuser. *Sw. frs.* **44.70.** (*Recd.* **18/2/55.**)

BURNETT, G. M. Mechanism of polymer reactions. New York **1954.** pp. xv + **493.** ill. (High Polymers, Vol. **3.**) ["Second version of Vol. **3**, replacing Mark-Raff, *High Polymeric Reactions.*"] Interscience. **$11.** (*Recd.* **1/2/55.**)

CANADA, DOMINION OF. *Department of Agriculture.* Guide to the chemicals used in crop protection. **2nd** edition. By HUBERT MARTIN. [London, Ontario] **1953.** pp. [iv] + **295.** (*Reference.*) [Loose-leaf.] The Department. **$1.**

DUBOS, RENE J. Biochemical determinants of microbial disease. Cambridge, Mass. **1954.** pp. viii + **152.** ill. Harvard Univ. Pr. **$3.50.** (*Recd.* **1/2/55.**)

GURD, FRANK H. *Editor.* Chemical specificity in biological interactions. New York **1954.** pp. xv + **234.** ill. (Memoirs of the University Laboratory of Physical Chemistry, Harvard University, No. **3.**) Academic Pr. **$6.** (*Recd.* **1/2/55.**)

INSTITUTE OF PETROLEUM. Standard methods for testing petroleum and its products. **14th** edition. London **1955.** pp. xxvii + **688.** ill. The Institute. **40s.** (*Recd.* **31/1/55.**)

MCADAMS, WILLIAM H. Heat transmission. 3rd edition. New York **1954.** pp. xiv + **532.** ill. McGraw-Hill. **$8.50.** (*Recd.* **1/2/55.**)

MANN, T. The biochemistry of semen. London **1954.** pp. xiv + **240.** ill. (Methuen's Monographs on Biochemical Subjects.) Methuen. **16s.** (*Recd.* **1/2/55.**)

MOLLOY, E., and CARR, E. *Editors.* Chemical engineering instruments and control methods. London **1954.** pp. x + **182.** ill. Newnes. **21s.** (*Recd.* **1/2/55.**)

OTT, EMIL, SPURLIN, HAROLD M., and GRAFFLIN, MILDRED W. *Editors.* Cellulose and cellulose derivatives. **2nd** edition. Part I. New York **1954.** pp. xvi + **509.** ill. (High Polymers, Vol. **5.**) Interscience. **$12.** (*Recd.* **1/2/55.**)

RIDDLE, EDWARD H. Monomeric acrylic esters. New York **1954.** pp. vii + **221.** ill. Reinhold. **$5.** (*Recd.* **1/2/55.**)

ROBERTSON, ANDREW JOHN BLACKFORD. Mass spectrometry. London **1954.** pp. [vi] + **135.** ill. (Methuen's Monographs on Chemical Subjects.) Methuen. **8s. 6d.** (*Recd.* **1/2/55.**)

RUTGERS, A. J. Physical chemistry. London **1954.** pp. xix + **804.** ill. Interscience. **58s.** (*Recd.* **1/2/55.**)

SCHOLL, A. W., and YOUNG, RICHARD L. Sulphur; a bibliography of analytical methods. [Huntington, W. Va. **1954.**] pp. [iii] + **324.** (*Reference.*)

SKINNER, GORDON, JOHNSTON, HERRICK L., and BECKETT, CHARLES. Titanium and its compounds. A review of the literature on thermal, structural, electrical, magnetic and other physical properties. Columbus, Ohio **1954.** pp. iii + **174.** ill. Herrick L. Johnston Enterprises. **$5.** (*Recd.* **18/2/55.**)

VON HIPPEL, ARTHUR R. Dielectrics and waves. New York **1954.** pp. xii + **284.** ill. Wiley. **$16.** (*Recd.* **1/2/55.**)

WINSOR, P. A. Solvent properties of amphiphilic compounds. London **1954.** pp. ix + **207.** ill. Butterworths. **40s.** (*Recd.* **1/2/55.**)

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Oxford.	L. A. K. Staveley, M.A., Inorganic Chemistry Laboratory, South Parks Road, Oxford.
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Sheffield.	H. J. V. Tyrrell, M.A., B.Sc., Chemistry Department, The University, Sheffield, 10.
South Africa.	Professor W. Pugh, Ph.D., B.Sc., F.R.I.C., Chemistry Department, University of Cape Town, Rondebosch, S. Africa.
Southampton.	N. B. Chapman, M.A., Ph.D., Department of Chemistry, The University, Southampton.
South Wales.	K. W. Sykes, M.A., B.Sc., D.Phil., Department of Chemistry, University College, Singleton Park, Swansea.

PROCEEDINGS

OF THE

CHEMICAL SOCIETY

SCIENTIFIC MEETINGS DURING JUNE, 1955

LONDON.

Thursday, June 2nd, 1955, at 7.30 p.m.

Centenary Lecture, **Chemical Effects of Steric Strain,** by Professor H. C. Brown, Ph.D. To be given in the Rooms of the Society, Burlington House, W.1.

OXFORD.

Monday, June 6th, 1955, at 8.15 p.m.

Official Meeting and Joint Meeting with the Alembic Club. Lecture by Sir Robert Robinson, O.M., F.R.S. To be held in the Physical Chemistry Laboratory, South Parks Road, Oxford.

OFFICIAL ANNOUNCEMENTS

DEATHS.

The Council regrets to announce the deaths of the following Fellows:

	Elected.	Died.
William Godden (Bucksburn)	Feb. 21st, 1907.	Sept. 3rd, 1954.
John Edwin Mackenzie (Edinburgh)	June 17th, 1897.	Feb. 5th, 1955.
Henry Wren (Worthing)	July 5th, 1906.	March 2nd, 1955.

CONGRATULATIONS

The President has conveyed the congratulations of the Society to the following Fellows who were elected to the Fellowship of the Royal Society on March 17th, 1955:

Alexander Fleck (London).
Donald Holroyde Hey (London).
John Wilfrid Linnett (Oxford).
Frederick Clifford Tompkins (London).

ACKNOWLEDGMENTS.

The thanks of the Society have been conveyed to Dr. H. A. Piggott for a gift of the Society's publications.

ELECTION OF NEW FELLOWS

The following 90 candidates were elected Fellows of the Society on March 17th, 1955:

Robin Arnold.
Charles Alan Bartram.
Ivor Donovan Beall.
Athelstan Laurence Johnson Beckwith.
Daniel Adzei Bekoe.
Milos Bil.
Yos Bunnag.
Margaret Anne Mercer Cameron.
Peter Gillis Clay.
Norman Alfred Coats.
Albert Coenders.
Theodore Cohen.
Charles George Bernard Cole.
Colin Bertie Cotterill.
Kevin John Crowley.
David Davidson.
Anthony Geoffrey Davies.
Leslie Scott Dent.
David William Dicker.
Derek Alan Dominey.
David Norman Edgington.
Pauline Marjorie Everitt.
Alan Richard Eyres.
Brian Orlando Field.
Joseph Fugger.
Melvin Joseph Goldstein.
John Alan Grace.
Jerome Newton Haimsohn.
George E. Hall.
Manzur-u-Haque Hashmi.
Hans Hirschmann.
Frank Brian Hollows.
Anthony Holt.
Michael Daintry Johnson.
Irving J. Krems.
J. Paul Kurath.
Stanley Kushinsky.
Howard Morgan Edward Leyshon.
Maria Lipp.
Lawrence Henry Charles Lunts.
Ian Hugh McEwan.
Henry C. Marks.
Arlen B. Mekler.
Holly Edgar Mertel.
David Anderson Miller.
John Milsted.
Fatima Minhaj.
Raymond Jackson Moss.
William Everett Neptune.
Peter Edward Newallis.
Patrick Nield.
Richard Oswald Chandler Norman.
Heinrich Noth.
John Francis O'Sullivan.
Croombe Frank Pensom.
Peter John Placito.
Jan Eilif Lehm Kahl Stoud Platou.
Srinivasa Rajagopalan.
Nolan Earle Richards.
Hugh Leithead Roberts.
Robert Robinson.
Ian Henry Rogers.
Jan Axel William Rosell.
Frank George Rothman.
Felix Schild.
Norman Senior.
Harrison Massey MacDougall Shearer.
Henryk Silberman.
James Christopher Phillips Sly.
Theodore Stephen Soddy.
Isidore Stelzer.
Donald Richard Stranks.

Patrick D. Sullivan.
Walter J. Sydor.
Saburo Tamura.
Michael Eric Upcott Taylor.
John Meurig Thomas.
Peter James Thomas.
Colin Topliss.
Edmond René Toromanoff.
Barry Maurice Waller Trapnell.
Shojiro Uyeo.
Srinivasa Varadarajan.
Pramode Verma.
George Raymond Whalley.
Robert Winslow White.
Anthony John Wicken.
James Richard Wolfe.
Haruaki Yajima.
John Russell Yates.

ELECTIONS TO COUNCIL 1955—56.

At the Annual General Meeting held on April 1st, 1955 the election of the following to vacancies on the Council for 1955—56 was announced:

Honorary Secretary.

PROFESSOR F. BERGEL.

Vice-Presidents who have not filled the Office of President.

PROFESSOR M. STACEY.
SIR ALEXANDER TODD.

Elected Ordinary Members of Council: Constituency I (South-East England)

DR. D. W. ADAMSON.
DR. A. W. JOHNSON.
DR. W. WILD.
DR. G. T. YOUNG.

Constituency II (Central and South-West England and South Wales)

DR. F. H. POLLARD.

Constituency III (North-West England, North Wales, and The Isle of Man)

DR. G. R. BARKER.
DR. A. HICKLING.

Constituency V (Scotland)

PROFESSOR F. BELL.

To fill the vacancy among the Ordinary Members of Council for Constituency I caused by the appointment of Professor F. Bergel as an Honorary Secretary, the Council has, in accordance with Bye-Law 42, nominated Dr. A. Maccoll to hold office for one year.

JOURNAL REPRINT SERVICE.

In view of the very small response from Fellows wishing to take advantage of the *Journal Reprint Service*, it has been decided that this service should be terminated as from December 31st, 1955.

INTERNATIONAL CONGRESS ON CATALYSIS IN 1956.

An International Congress on Catalysis will be held in Philadelphia, Pennsylvania, from September 10th to 14th, 1956. It will be sponsored jointly by The National Science Foundation, The Catalysis Club of Philadelphia, The Catalysis Club of Chicago, and the University of Pennsylvania. This will be the first international meeting on catalysis to be held in America, and will cover heterogeneous as well as subjects of homogeneous catalysis and biocatalysis. All papers presented at the meeting will be preprinted to facilitate discussion.

The National Science Foundation has given a grant to the Sponsors of the Congress to enable them to offer some financial support to scientists who could not otherwise attend the meeting. Additional funds are being raised by subscription. Professor Hugh S. Taylor, Mr. Eugene J. Houdry, and Sir Eric Rideal have been named honorary chairmen

of the Congress. Dr. A. Farkas is in charge of programme arrangements. All enquiries concerning this meeting and its organisation should be directed to Dr. H. Heinemann, Executive Secretary of the International Congress on Catalysis, c/o Houdry Process Corporation, P.O. Box 427, Marcus Hook, Pennsylvania, U.S.A.

MINUTES OF SCIENTIFIC MEETINGS

Minutes of a

SCIENTIFIC MEETING

held at Burlington House, on Thursday, 17th March, 1955, at 7.30 p.m.

The President, PROFESSOR W. WARDLAW, C.B.E., D.Sc., F.R.I.C., was in the Chair.

MINUTES.

The Minutes of the Scientific Meetings held at Burlington House and the University Chemical Laboratory, Cambridge, on February 17th and 18th, respectively, were read, and were confirmed and signed.

FORMAL ADMISSION OF FELLOWS.

The following were admitted Fellows of the Society: J. Richard Armstrong, Yvonne M. Beasley, G. H. Bull, T. C. Stening, G. H. Baker, R. E. Deriaz.

PEDLER LECTURE.

After a brief introduction the President called upon Professor E. L. Hirst, M.A., D.Sc., LL.D., F.R.S., to deliver the Pedler Lecture entitled "Some Problems in the Chemistry of the Hemicelluloses."

At the conclusion of the Lecture, a vote of thanks to Professor Hirst, proposed by the Chairman, was carried with acclamation.

LIST OF APPLICATIONS FOR FELLOWSHIP

(*Fellows wishing to lodge objection to the election of these candidates should communicate with the Honorary Secretaries within ten days of the date of publication of the* Journal *for April,* 1955. *Such objections will be treated as confidential. The forms of application are available in the Library.*)

Ainscough, John Brian, B.Sc. (Leeds), A.R.I.C. British. Department of Physical Chemistry, The University, Leeds, 2. Research Student. *Signed by:* F. S. Dainton, E. F. Caldin.

Arthur, William Robert Brinley, B.Sc. (Wales). British. 36, St. Gwlady's Avenue, Bargoed, Glam. Research Student. *Signed by:* E. Whittle, N. M. Cullinane.

Ashbrook, John Stanley. British. 62, Hodgsons Road, Blyth, Northumberland. Senior Works Chemist at Northern Gas Board, Redheugh Works, Gateshead. *Signed by:* J. K. Blacklock, S. Hornsby.

Auslander, Friederike Fedora (Mrs.), D.Chem. and D.Pharm (Vienna). Israeli. Haifa, P.O.B. 1253, Israel. Scientific Manager of "Hillel" Remedy Factory, Haifa-Bay. *Signed by:* H. L. Bernstein, D. Ginsburg.

Aylett, Bernard John, M.A. and Ph.D. (Cantab.). British. 20, Donmouth Road, Bridge of Don, Aberdeen. Chemistry Assistant at University of Aberdeen. *Signed by:* P. Meares, H. F. W. Taylor.

Banister, Arthur James, B.Sc. (Bris.). British. 62, Muller Road, Horfield, Bristol, 7. Post-Graduate Research Student. *Signed by:* F. H. Pollard, P. Woodward.

Bates, Irene. British. Flat 4, 7, Edgerton Mansions, Brompton Road, London, S.W.3. Student. *Signed by:* C. M. French, R. F. Garwood.

Batey, William. British. 30, Rosamond Place, Blyth, Northumberland. Student. *Signed by:* F. J. McQuillin, R. Raper.

Batstone, Jean Margaret, B.Sc. (Lond.). British. 3M, Grove End House, St. Johns Wood Road, London, N.W.8. Research Student. *Signed by:* J. W. Smith, K. E. Howlett.

Batt, Leslie. British. 50, Berkeley Avenue, Greenford, Middlesex. Student at University College, Swansea. *Signed by:* K. W. Sykes, B. G. Gowenlock.

Bender, Myron Lee, B.S. and Ph.D. (Purdue). American. Department of Chemistry, Illinois Institute of Technology, Chicago 16, Illinois, U.S.A. Assistant Professor. *Signed by:* J. Hine, E. Grovenstein, jun.

Berkovic, Samuel, Ing.Chem. (Praha). Israeli. P.O.B. 1, Kiriath Motzkin, Israel. Scientific Department, Israeli Ministry of Defence. *Signed by:* E. Bergmann, D. Ginsburg.

Bevan, Francis van Massy. British. 26, Ellerton Road, London, S.W.18. Student at King's College. *Signed by:* S. H. Harper, J. Boulton.

Bonneywell, Kathleen Molly (Mrs.). British. 7, Parkview Road, Addiscombe, Croydon, Surrey. Research Librarian. *Signed by:* H. C. Happold, J. W. Lowry.

Burnett, George Murray, B.Sc. and Ph.D. (Aberd.), D.Sc. (Birm.). British. Chemistry Department, The University, Old Aberdeen. Professor. *Signed by:* R. H. Thomson, R. B. Strathdee.

Burton, Michael Stephen. British. 8, Callary Road, Mount Merrion, Blackrock, Co Dublin, Eire. Student. *Signed by:* J. T. Edward, W. Cocker.

Carss, Beverley, B.Sc. (Dunelm). British. 10, Birchfield Road, Sunderland. Research Student at King's College, Newcastle-on-Tyne. *Signed by:* W. F. K. Wynne-Jones, J. Baddiley.

Casson, Donald Athelstan. British. 19, Parkcroft Road, West Bridgford, Nottingham. Undergraduate student at University of Nottingham. *Signed by:* N. N. Greenwood, A. R. Mathieson.

Chang, Shih, B.Sc. (Peking). Malayan Chinese. 7, Passmore Gardens, London, N.11. Research Student at King's College, London. *Signed by:* S. H. Harper, A. F. Chaplin.

Clarke, Clifford Brian, B.Sc. (Q.U.B.). British. 667, Lisburn Road, Belfast. Research Student at Queen's University, Belfast. *Signed by:* A. R. Pinder, R. G. R. Bacon.

Clarke, Roger Christopher. British. Tower House, 2, Ridgeway Road, Redhill, Surrey. Student at Queen Mary College, London. *Signed by:* M. J. S. Dewar, W. J. Hickinbottom.

Collier, Jeremy Austin Grey. British. Balliol College, Oxford. Undergraduate. *Signed by:* L. A. K. Staveley, W. A. Waters.

Collins, Joseph Charles, jun., B.S. (Wayne). American. 2011, Monroe Street, Madison, Wisconsin, U.S.A. Predoctorate Graduate Student at University of Wisconsin. *Signed by:* R. Pappo, W. D. Wood, H. L. Goering.

Collins, Ruth Margaret. British. Ravensmead, Gillas Lane, Houghton-le-Spring, Co. Durham. Student at St. Anne's College, Oxford. *Signed by:* F. J. Stubbs, M. L. Tomlinson.

Coplin, Donald Joseph. British. Hugh Stewart Hall, University Park, Nottingham. Student. *Signed by:* C. C. Addison, W. E. Addison.

Court, Michael Norman. British. 29, Henleaze Road, Westbury-on-Trym, Bristol 6. Student at University of Bristol. *Signed by:* P. Woodward, W. J. Dunning.

Cowley, Brian Richard. British. 44, East Drive, Carshalton Beeches, Surrey. Undergraduate at Balliol College, Oxford. *Signed by:* L. A. K. Staveley, R. P. Bell.

Cragg, Jeffery, B.Sc. (Nott.). British. 79, Beeston Fields Drive, Bramcote, Notts. Postgraduate Research Student at University of Leeds. *Signed by:* S. D. Holdsworth, E. Rothstein.

Dorken, Derrick Henry, B.Pharm. (Lond.). British. 2, Canons Road, Ware, Hertfordshire. Industrial Chemist. *Signed by:* W. E. Willmott, A. H. Beckett.

Doughty, Thomas Joseph, A.R.I.C. British. 22, Adela Road, Runcorn, Cheshire. Senior Works Chemist with Ward Blenkinsop and Co. Ltd. *Signed by:* W. Kelly, H. G. Dickenson.

Dunn, Jeanne Monica, B.Sc. (Lond.). British. 25, Anne Boleyn's Walk, Cheam, Surrey. Research Chemist. *Signed by:* J. D. Johnson, M. J. Soulal.

Emmons, William David, B.S. (Minn.), Ph.D. (Ill.). American. Rohm and Haas, Co., Huntsville, Alabama, U.S.A. Chemist. *Signed by:* M. F. Hawthorne, G. B. Lucas.

Fenlon, Arthur Thomas, B.Sc. (Liv.). British. 48A, Swanside Road, Liverpool, 14. Assistant Chemist with Kodak, Ltd. *Signed by:* H. Bradbury, G. E. Derome.

Ford, Martin Graham. British. 25, Crawford Gardens, Palmers Green, London, N.13. Student. *Signed by:* M. J. S. Dewar, D. M. Grove.

Freeman, Jeremiah Patrick, M.S. and Ph.D. (Ill.). American. Rohm and Haas Co., Redstone Arsenal Research Division, Huntsville, Alabama, U.S.A. Research Chemist. *Signed by:* G. Lucas, K. S. McCallum.

Fry, Douglas James, B.Sc. (Lond.), A.R.I.C. 36, Tresco Gardens, Ilford, Essex. Deputy Head of Renwick Laboratory, Ilford, Ltd. *Signed by:* J. D. Kendall, G. F. Duffin.

George, Peter William Grover. British. South Stoneham House, Swaythling, Southampton. Student. *Signed by:* N. B. Chapman, N. K. Adam.

Gibson, John Frederick. British. 17, Westgate Bay Avenue, Westgate-on-Sea, Kent. Student at University of Southampton. *Signed by:* N. B. Chapman, R. E. Parker.

Gibson, Martin Stewart, M.A. and D.Phil. (Oxon.). British. Exeter College, Oxford. Research Chemist. *Signed by:* L. A. K. Staveley, J. A. Barltrop.

Gilks, Stanley William. British. 104, Priory Gardens, Highgate, N.6. Undergraduate at Queen Mary College. *Signed by:* M. J. S. Dewar, W. J. Hickinbottom.

Grant, Mervyn Stuart. British. 49, Beaumont Court, Upper Clapton Road, London, E.5. Chemistry Student at Queen Mary College. *Signed by:* M. F. Ansell, D. M. Grove.

Green, John Wilson, Ph.D. (Princeton), M.S. (Penn.). American. The Institute of Paper Chemistry, Appleton, Wisconsin, U.S.A. Research Associate. *Signed by:* J. P. Butler, J. K. N. Jones.

Green, William John, B.Sc. and Ph.D. (Lond.). British. 138, Green Lanes, Stoke Newington, London, N.16. Section Leader in Rubber and Plastics Department, British Insulated Callender's Cables, Ltd. *Signed by:* W. Gerrard, M. F. Lappert.

Greig, Louise Elizabeth, M.Sc. (New Zealand). New Zealand. 39A, Ellesmere Avenue, Miramar, Wellington, E.4, New Zealand. Industrial Chemist. *Signed by:* S. N. Slater, W. S. Metcalf.

Guthrie, Roy David. British. 17, Kingscroft Road, Leatherhead, Surrey. Student at King's College, London. *Signed by:* S. H. Harper, L. Benjamin.

Hall, David, M.Sc. (New Zealand), A.N.Z.I.C. British. 26, Harcourt Green, Wantage, Berkshire. Research Fellow at A.E.R.E., Harwell. *Signed by:* B. J. Bowles, G. N. Walton.

Headridge, James Baillie, B.Sc. (Edin.). British. 13, Firth Crescent, Auchendinny, Penicuik, Midlothian. Research Student. *Signed by:* C. C. Miller, R. J. Magee.

Herbert, Amy Edith Jean. British. 8, Bath Street, Stoke-on-Trent, Staffs. Undergraduate at Oxford University. *Signed by:* L. A. K. Staveley, D. M. Hodgkin.

Heslop, Richard Beautyman, M.Sc. (Dunelm.), A.R.I.C. British. 27, Elmfield Grove, Newcastle-on-Tyne, 3. Lecturer at Rutherford College of Technology, Newcastle, 1. *Signed by:* P. L. Robinson, E. W. Mills.

Hill, Howard Dudley Crile, S.M. (M.I.T.). American. 624, Shadowlawn Avenue, Dayton, Ohio. Project Engineer in Materials Laboratory, Directorate of Research, Wright Air Development Center. *Signed by:* J. F. O'Brien, H. Rosenberg.

Hill, Ronald, M.A. (Cantab.). British. 61, Shinglewell Road, Erith, Kent. Instructor Lieutenant, Royal Navy. *Signed by:* M. J. Newlands, F. B. Kipping.

Hofer, Bruno, Dr.Phil. (Basle). Swiss. Im Steinenmüller 9, Neuewelt/BL, Switzerland. Research Chemist with J. R. Geigy, Ltd., Basle. *Signed by:* C. A. Grob, T. Reichstein.

Holroyd, Ronald, M.Sc. and Ph.D. (Sheffield). British. Imperial Chemical Industries, Ltd., Millbank, S.W.1, Chemist and Research Director. *Signed by:* W. Wardlaw, D. H. Hey, E. K. Rideal, J. L. Simonsen.

Houlihan, William Joseph, B.S. (Seton Hall Univ.). American. 308, Henry Street, South Amboy, New Jersey, U.S.A. Research Fellow at Rutgers University, New Brunswick. *Signed by:* W. T. Holfeld, J. S. Showell.

Ives, David Arthur John, B.Sc. (Lond.), A.R.C.S. British. 20, Fairfield Avenue, Ruislip, Middlesex. Research Student. *Signed by:* D. J. G. Ives, D. H. R. Barton.

Jenkinson, David Stewart, B.A., B.Sc., and Ph.D. (T.C.D.). Irish. Department of Agricultural Chemistry, The University, Reading, Berks. Assistant Lecturer. *Signed by:* J. Tinsley, C. Tyler.

Jewell, Robert Edwin, B.Sc. (Lond.). British. 43, Undercliff Road (West), Felixstowe, Suffolk. Research Chemist. *Signed by:* J. K. Bradley, A. L. Whynes.

Jones, David Neville, B.Sc. (Wales). British. 199, Tycroes Road, Tycroes, Ammanford, Carms. Research Student at University College of Swansea. *Signed by:* K. W. Sykes, G. H. R. Summers.

Jones, Michael John, B.Sc. (Lond.). British. 16, Fromondes Road, Cheam, Surrey. Chemist with British Industrial Solvents, Carshalton. *Signed by:* E. S. Pemberton, W. E. Cash.

Knight, Robert Hipwell, B.Sc. (Lond.). British. 11, Jerningham Road, New Cross, S.E.14. Demonstrator in Biochemistry Department. *Signed by:* C. J. W. Brooks, R. J. Townsend.

Krejci, Frantisek, Dr.Ing. (Prague). Czech. Vyzkumny ustav prumyslove chemie, Pardubice—Semtin, Czechoslovakia. Chief Chemist. *Signed by:* J. Weigner, F. Panzner.

Law, Harry Davis, B.A. (U.C.N.S.). British. 1, Clayton Road, Newcastle-under-Lyme, Staffs. Research Student. *Signed by:* R. C. Cass, I. T. Millar.

Lewin, Nathan. Polish. 30, Greencroft Gardens, Flat C, London, N.W.6. Student. *Signed by:* P. L. Wyvill, H. J. S. King.

Livingstone, Stanley Edward Mervyn Richard, B.Sc. and Ph.D. (N.S. Wales). British. 5, Parker Street, Rockdale, New South Wales, Australia. Lecturer at N.S. Wales University of Technology, Sydney. *Signed by:* C. M. Harris, R. L. Martin.

Lloyd, Lawrence, B.Sc. (Sheffield). British. 15, Craigweil Crescent, Stockton-on-Tees, Co. Durham. Research Student. *Signed by:* P. A. H. Wyatt, H. J. V. Tyrrell.

Lloyd, Peter Frederick, B.Sc. and Ph.D. (Birm.). British. 5, Preston Parade, Beeston, Leeds 11. Research Fellow at University of Leeds. *Signed by:* A. B. Foster, S. A. Barker.

Lott, Kenneth Alan Keeler. British. 267, Folkestone Road, Dover, Kent. Undergraduate at Southampton University. *Signed by:* N. B. Chapman, A. C. Riddiford.

Loveday, George William. British. 62, Hillingdon Street, Walworth, S.E.17. Student at Queen Mary College, London. *Signed by:* M. J. S. Dewar, W. J. Hickinbottom.

Marshall, Raymond, B.Sc. (Southampton). British. 69, Welbeck Avenue, Highfield, Southampton, Hants. Research Student at Southampton University. *Signed by:* N. B. Chapman, M. C. R. Symons.

Matthews, Virgil Edison, M.S. and Ph.D. (Chicago). American. 308, Donnally Street, Charleston 1, West Virginia, U.S.A. Research Chemist at Process Development Laboratories, Carbide and Carbon Chemical Co. *Signed by:* M. S. Kharasch, K. D. Kopple.

Meyer, Barbara Lily (Mrs.), B.Sc. (Lond.). British. 5, Pembridge Crescent, Bayswater, W.11. Library and information work for Chemical Industry Administration, Shell Petroleum Co. Ltd. *Signed by:* N. A. Iliff, P. J. Garner.

Miller, Charles James, B.Sc. (N.S.W. Univ. of Tech.). Australian. 35, Yangoora Road, Belmore, N.S. Wales, Australia. Chemistry Teacher. *Signed by:* G. W. K. Cavill, R. M. Gascoigne.

Morris, John Dudley. British. White Cottage, Ridgeway, Pyrford, Woking, Surrey. Undergraduate at Balliol College, Oxford. *Signed by:* L. A. K. Staveley, R. P. Bell.

Morrison, George Anderson. British. 145, Gourlay Street, Springburn, Glasgow, N. Student. *Signed by:* D. S. Payne, S. C. Abrahams.

Neely, Wesley Brock, Ph.D. (Michigan State Coll.). Canadian. Research Department, G. D. Searle and Co., Chicago, 80, Illinois, U.S.A. Research Associate at University of Birmingham, England. *Signed by:* J. C. Tatlow, W. G. Overend, E. J. Bourne.

Nelson, Kay LeRoi, Ph.D. (Purdue). American. Department of Chemistry, Wayne University, Detroit, 1, Michigan, U.S.A. Assistant Professor. *Signed by:* C. Djerassi, S. Kirschner.

Newnham, Philip Howard James. British. Michelmersh, Havant Road, Emsworth, Hants. Scientific Assistant, Royal Naval Scientific Service. *Signed by:* J. E. Le Surf, D. J. Godfrey.

Nicholls, Barry, B.Sc. (Manc.). British. 26, Woodstock Drive, Worsley, Walkden, Manchester. Post Graduate Research Worker. *Signed by:* G. R. Barker, H. B. Henbest.

Norton, Charles Joseph, B.S. (Purdue), M.A. (Harvard). American. 39, Perkins Hall, Harvard University, Cambridge 38, Massachusetts, U.S.A. Graduate Student. *Signed by:* R. F. Hutton, B. L. Shapiro, R. Breslow.

Ouderkirk, John Thomas, A.B. (Hamilton Coll). American. 410, Linn Street, Ithaca, New York, U.S.A. Student at Cornell University. *Signed by:* A. Meinwald, R. C. Springborn.

Page, Frederick Granville. British. 24, Willowsbrook Road, Hurst Green, Blackheath, Birmingham. Analytical Chemist with Albright and Wilson, Ltd. *Signed by:* V. R. Switsur, D. B. Whitehouse.

Penny, Joyce Margaret (Mrs.). British. 75, Marylebone Lane, London, W.1. Chemistry Student at Bedford College. *Signed by:* E. E. Turner, D. M. Hall.

Perry, Ivy Elizabeth, B.Sc. (Lond.). British. 15, Southend Road, Beckenham, Kent. Research Chemist with Whiffen and Sons, Ltd., Fulham. *Signed by:* E. Glynn, J. T. W. Mann.

Phoenix, Leslie, B.Sc. (Wales). British. 108, Pentre Lane, Llay, Nr. Wrexham, N. Wales. Research Worker at Imperial Chemical Industries, Ltd. *Signed by:* J. R. Carding, W. J. Whelan, J. G. Roberts.

Pinkus, Jack Leon, B.S. (Syracuse). American. Chemistry Department, University of Southern California, Los Angeles 7, California, U.S.A. Student. *Signed by:* N. Kharasch, D. R. Hogg, M. C. Kloetzel.

Popp, Frank Donald, B.S. (Rensselaer Polytechnic Inst.). American. Chemistry Department, University of Kansas, Lawrence, Kansas. Graduate Student and Teaching Assistant. *Signed by:* W. E. McEwen, J. Kenyon.

Prevedorou, Chrysoula Caliope A., B.Sc. (Alexandria). Greek. Birkbeck College, Chemistry Department, Malet Street, W.C.1. Postgraduate Student. *Signed by:* J. D. Swanwick, D. C. Bradley.

Pringle, William. British. Post Office, Grange Villa, Chester-le-Street, Co. Durham. Student at King's College, Newcastle-on-Tyne. *Signed by:* R. Raper, F. J. McQuillin.

Ramsden, Robert Henry. British. Brasenose College, Oxford. Undergraduate. *Signed by:* L. A. K. Staveley, J. A. Barltrop.

Relyea, Douglas Irving, M.S. (Cornell), Ph.D. (South Carolina). American. Department of Chemistry, University of Wisconsin, Madison, 6, Wisconsin, U.S.A. Post-doctoral Fellow. *Signed by:* D. F. DeTar, H. L. Goering, R. Pappo.

Rhodes, Elizabeth, B.Sc. (Lond.). British. 5, Park Crescent, Portland Place, London, W.1. Development Research Chemist with British Drug Houses. *Signed by:* H. T. Young, G. E. H. Skrimshire.

Robbins, Raymond Frank, B.Sc. and Ph.D. (Wales). British. 20, Neville Crescent, Acton, Wrexham. Research Chemist. *Signed by:* G. V. Phillips, A. M. Spivey.

Rogers, Vernon. British. 48, Old Henry Street, Neath, S. Wales. Student at Bristol University. *Signed by:* P. Woodward, W. J. Dunning.

Ryback, George. Polish. 150, Sinclair Road, London, W.14. Undergraduate at New College, Oxford. *Signed by:* L. A. K. Staveley, G. Saville.

Sallabanks, Lawrence George Albert. British. 12, Lindfield Gardens, Hampstead, London, N.W.3. Chemical Assistant to Base Metal Products, Ltd., Wembley, Middlesex. *Signed by:* J. W. H. Oldham, P. A. Claret.

Salomaa, Pentti Antero, M.Sc. and Ph.D. (Turku). Finnish. Martink. 7 D 62, Turku, Finland. Lecturer at University of Turku. *Signed by:* E. D. Hughes, A. G. Davies.

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5542. "Fundamental properties of cross-linked poly(methacrylic acid) ion-exchange resins." By P. G. Howe and J. A. Kitchener.

5685. "An empirical bond additivity method for the calculation of diamagnetic susceptibilities of simple organic molecules." By C. M. French and D. Harrison.

5700. "1-Phenylnaphthalenes. Part II. The cyclisation of ethyl hydrogen $\gamma\gamma$-di-*o*-methoxyphenyl- and $\gamma\gamma$-di-*p*-methoxyphenyl-itaconate to the corresponding 1-phenylnaphthalenes." By F. G. Baddar, Lanson S. El-Assal, and (Mrs.) Victorine B. Baghos.

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5937. "The kinetics of alkyl–oxygen fission in ester hydrolysis. Part II. *tert.*-Butyl 2 : 4 : 6-trimethylbenzoate in aqueous acetone." By V. R. Stimson.

5939. "Five-covalent terpyridyl complexes of bivalent metals. Part I. The stereochemistry of the zinc, cadmium, and copper compounds." By D. E. C. Corbridge and E. G. Cox.

5951. "The influence of electrolytic dissociation upon rates of reactions. Part I. The common-ion effect in the hydrolysis of *tert.*-butyl bromide." By G. R. Nash and C. B. Monk.

5954. "Triterpenoids. Part XXXIII. The constitution of *cyclo*laudenol." By J. A. Henry, D. S. Irvine, and F. S. Spring.

5960. "Synthetic plant hormones. Part III. Aryloxymethylphosphonates." By (Miss) M. H. Maguire and G. Shaw.

5971. "The reaction of triethyl phosphite with phenylmagnesium bromide." By (Miss) M. H. Maguire and G. Shaw.

5988. "The conversion of *cyclo*hexanone into *gem*-disubstituted *cyclo*hexanes." By W. Parker and R. A. Raphael.

5998. "Esters containing phosphorus. Part XI. Esters of phosphorofluoridic acid." By H. Goldwhite and B. C. Saunders.

51007. "Possible intermediates for the synthesis of simple analogues of steroids." By Edward R. Clark and P. F. Epstein.

51011. "The kinetics and mechanism of the polymerization of ethyleneimine." By W. G. Barb.

51012. "Some aspects of the polymerization and depolymerization of *N*-substituted ethyleneimines." By W. G. Barb.

51013. "Interconversions of itaconic and citraconic anhydrides in amine solutions." By W. G. Barb.

51016. "Total synthesis of ricinoleic acid." By L. Crombie and A. G. Jacklin.

51017. "Hydrazine. Part XI. *N*-Methyl aldazinium and ketazinium chlorostannates derived from methylhydrazine." By M. Lamchen and A. M. Stephen.

51018. "Molecular deformation in 3 : 4-5 : 6-dibenzophenanthrene." By C. A. Coulson and S. Senent.

51019. "Approximate potential function for the out-of-plane vibrations of ethylene, and of aromatic molecules such as benzene and naphthalene." By C. A. Coulson and S. Senent.

6002. "The chemistry of *Aristolochia* spp. Part II. Some rearrangements of aristolactone." By J. B. STENLAKE and W. D. WILLIAMS.

6004. "Infrared spectra and crystallinity, Part I. Polyesters." By W. H. T. DAVISON and P. J. CORISH.

6005. "Infrared spectra and crystallinity. Part II. αω-Dicarboxylic acids." By P. J. CORISH and W. H. T. DAVISON.

6011. "Reactions of α-halogeno-ketones with aromatic compounds. Part II. Reactions of 2-chloropentan-3-one, 4-chlorohexan-3-one, and *s*-dichloroacetone with phenol and its ethers." By S. HUSAIN ZAHEER, BALDEV SINGH, BHARAT BHUSHAN, I. K. KACKER, K. RAMACHANDRAN, and N. SHANMUKHA RAO.

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6029. "The activation of carbon–carbon double bonds by cationic catalysts. Part I. The dimerisation of 1 : 1-diphenylethylene." By ALWYN G. EVANS, N. JONES, and J. H. THOMAS.

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6033. "The synthesis of compounds with potential antifolic acid activity. Part III. 3 : 6-Diaminoquinoxaline and derived compounds." By T. S. OSDENE and G. M. TIMMIS.

6034. "The synthesis of compounds with potential antifolic acid activity. Part IV. 3 : 6-Diaminopyrido(2 : 3)pyrazines." By T. S. OSDENE and G. M. TIMMIS.

6035. "The synthesis of compounds with potential antifolic acid activity. Part V. 4 : 7-Diamino- and 2 : 4 : 7-triamino-pteridine and their derivatives." By T. S. OSDENE and G. M. TIMMIS.

6036. "The synthesis of 2 : 4-diamino-7-hydroxypteridine and its 6-carboxylic acid." By T. S. OSDENE and G. M. TIMMIS.

6039. "Nitramines and nitramides. Part VIII. Additional measurements of the rate of decomposition of primary nitramines, and the evidence for general acid catalysis." By I. N. DENTON and ALEX. H. LAMBERTON.

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6050. "The configuration of heterocyclic antimony compounds. Part III. Resolution and racemisation of new members of the 9-stibiafluorene series." By I. G. M. CAMPBELL and D. J. MORRILL.

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6059. "Methyl-substituted αβ-unsaturated acids. Part II." By A. S. BAILEY, N. POLGAR, F. E. G. TATE, and A. WILKINSON.

6062. "Observations on taraxerol (skimmiol)." By C. J. W. BROOKS.

6066. "The preparation of some *N*-alkyl- and *NN*-dialkyl-*p*-nitrosoanilines." By J. WILLENZ.

6067. "*p*-Nitrosoaniline." By J. WILLENZ.

6068. "Synthetic experiments in the *cyclo*heptatrienone series. Part VI. Further reactions of 3-hydroxytropone." By A. W. JOHNSON and M. TISLER.

6069. "A derivative of *cyclo*heptatrienylium (tropylium) bromide." By A. W. JOHNSON, A. LANGEMANN, and M. TISLER.

6070. "The Orton rearrangement. Part I. The preparation and properties of *N*-bromo- and *N*-chloro-2 : 6-dimethylacetanilide." By M. J. S. DEWAR and J. M. W. SCOTT.

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6083. "Triterpenoids. Part XXXV. The reactions of 12-oxo*iso*ursa-9(11) : 14-dien-3β-yl acetate." By J. DOUGLAS EASTON and F. S. SPRING.

6084. "Triterpenoids. Part XXXVI. Reactions of 18α-olean-12-en-3β-ol derivatives and observations on the stereochemistry of α-amyrin." By C. G. ALLAN and F. S. SPRING.

6085. "The synthesis and reactions of branched-chain hydrocarbons. Part VII. The preparation and pinacol rearrangement of some αβ-acetylenic ditertiary glycols." By M. F. ANSELL, W. J. HICKINBOTTOM, and A. A. HYATT.

6086. "Perfluoroalkyl derivatives of nitrogen. Part I. Perfluoro-2-methyl-1 : 2-oxazetidine and perfluoro(alkylenealkylamines)." By D. A. BARR and R. N. HASZELDINE.

6087. "The alkaloids of *Picralima nitida*, Stapf, Th. and H. Durand. Part III. A note on akuammicine and *pseudo*akuammicine." By SIR ROBERT ROBINSON and A. F. THOMAS.

6089. "The structure of the oligosaccharides produced by the enzymic breakdown of pectic acid. Part II." By J. K. N. JONES and W. W. REID.

6090. "The reactions of highly fluorinated organic compounds. Part IX. 1*H*-Decafluoro-4-trifluoromethyl*cyclo*hexane, nonafluoro-4-trifluoromethyl*cyclo*hex-1-ene, and perfluoro-(3-methyladipic) acid." By G. B. BARLOW, M. STACEY, and J. C. TATLOW.

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6099. "Oenanthotoxin and cicutoxin. Part II. The synthesis of (±)-cicutoxin and of oenanthetol." By (MISS) B. E. HILL, B. LYTHGOE, S. MIRVISH, and S. TRIPPETT.

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6114. "2-Alkoxypropenes." By H. P. CROCKER and R. H. HALL.

6118. "The allegedly isomeric diazo-derivatives from 'dehydrothioparatoluidine' (2-*p*-aminophenyl-6-methylbenzothiazole)." By M. ARONEY and R. J. W. LE FÈVRE.

6120. "Organometallic compounds of the alkali metals. Part V. The non-radical decomposition of *n*-butyl-lithium." By D. BRYCE-SMITH.

6122. "Stability sequence of five stereoisomeric perhydro-1 : 4-dioxophenanthrenes." By P. A. ROBINS and JAMES WALKER.

6123. Hydration of a bridged α-diketone." By R. H. BURNELL and W. I. TAYLOR.

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6126. "Reactions of α-thioacylamino-acids. Their conversion into thiazolones, and derivatives thereof." By J. B. JEPSON, ALEXANDER LAWSON, and (MISS) V. D. LAWTON.

6127. "Steroids and Walden inversion. Part XXV. A kinetic study of the methanolysis of cholesteryl toluene-*p*-sulphonate in the presence of methoxide ions." By C. W. SHOPPEE and D. T. WESTCOTT.

6128. "Quinoxaline studies. Part I. The methylation of some 2- and 3-hydroxyquinoxalines." By G. W. H. CHEESEMAN.

6131. "Ionophoresis of carbohydrates. Part II. Some pyranose and furanose derivatives of D-glucose." By A. B. FOSTER and M. STACEY.

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6135. "Pteridine studies. Part VI. The ultraviolet and infrared absorption spectra of the monosubstituted pteridines." By S. F. MASON.

6136. "The synthesis and reactions of branched-chain hydrocarbons. Part VIII. The pinacol rearrangement of an aliphatic tetraol." By M. F. ANSELL, W. J. HICKINBOTTOM, and A. A. HYATT.

6138. "Cafestol. Part I." By R. D. HAWORTH, A. H. JUBB, and J. MCKENNA.

6149. "The synthesis of trypanocides. Part III. 4-Amino-6-(4-amino-1 : 6-dimethylpyrimidinium-2-amino)-1 : 2-dimethylquinolinium salts and related compounds." By (the late) F. H. S. CURD and (MISS) D. N. RICHARDSON.

6150. "The synthesis of trapanocides. Part IV. The attempted preparation of 4-amino-6-(6-amino-1 : 2-dimethylpyrimidinium-4-amino)-1 : 2-dimethylquinolinium di-iodide." By (the late) F. H. S. CURD and (MISS) D. N. RICHARDSON.

6151. "The synthesis of trypanocides. Part V. A rearrangement of some 6-amino-1-methylpyrimidinium salts, and the synthesis of 4-amino-1 : 2-dimethyl-6-(6-methylaminopyrimidinium-4-amino)-1 : 2-dimethylquinolinium di-iodide." By H. C. CARRINGTON, (the late) F. H. S. CURD, and (MISS) D. N. RICHARDSON.

6166. "A Wolff–Kishner reduction procedure for sterically hindered carbonyl groups." By D. H. R. BARTON, D. A. J. IVES, and B. R. THOMAS.

6167. "The degradation of carbohydrates by alkali. Part XI. 4-*O*-Methyl derivatives of glucose and fructose." By J. KENNER and G. N. RICHARDS.

ADDITIONS TO THE LIBRARY

I. *Donations*

A. *Books.*

SPEAKMAN, J. C. An introduction to the electronic theory of valency. 3rd edition. London 1955. pp. vii + 180. ill. 10*s.* 6*d.* (*Recd.* 2/3/55.) From the Publishers: Messrs. Edward Arnold, Ltd.

B. *Pamphlets.*

INSTITUT DE BIOLOGIE PHYSICO-CHIMIQUE. Cérémonie en l'honneur du XXVe anniversaire de l'Institut de Biologie Physico-Chimique, 2e fondation Edmond de Rothschild pour le développement de la recherche scientifique. Paris 1953. pp. 28.

LEBEAU, PAUL, and GIRARD, PIERRE. Hommage à Jean Perrin. Paris 1950. pp. 25.

II. *By purchase*

BERGERON, JACQUES. Savons et détergents. Paris 1954. pp. 199. ill. Armand Colin. *frs.* 250.

INTERNATIONAL SYMPOSIUM ON THE REACTIVITY OF SOLIDS, Gothenburg 1952, Proceedings. Parts I and II. Gothenburg 1954. pp. 1102. ill. £5. (*Recd.* 26/2/55.)

HOUWINK, R. *Editor.* Chemie und Technologie der Kunststoffe. 3rd edition. Vol. 1. Chemische und physikalische Grundlagen sowie Prüfungsmethoden. Leipzig 1954. pp. xvi + 813. ill. Akademische Verlagsgesellschaft. *DM* 56. (*Recd.* 24/3/55.)

LETTRÉ, H., TSCHESCHE, R., and FERNHOLZ, H. Über Sterine, Gallensäuren und verwandte Naturstoffe. 2nd edition. Vol. 1. Stuttgart 1954. pp. viii + 445. ill. (Sammlung chemischer und chemisch-technischer Beiträge, Neue Folge, Nr 29a.) Ferdinand Enke. *DM* 85. (*Recd.* 26/2/55.)

MANEGOLD, E. Kapillarsysteme. Vol. 1 (Grundlagen). Heidelberg 1955. pp. 763. ill. Strassenbau, Chemie und Technik Verlagsgesellschaft. *DM* 50. (*Recd.* 22/3/55.)

MORGAN, PHILLIP. *Editor.* Glass reinforced plastics. London 1955. pp. vii + 248. ill. Iliffe. 35*s.* (*Recd.* 1/3/55.)

RUBIN, B. A., and ARZICHOWSKAJA, E. W. Biochemische Charakteristik der Widerstandsfähigkeit der Pflanzen gegenüber Mikroorganismen. Berlin 1953. pp. [iv] + 87. ill. Akademie-Verlag. *DM* 8. (*Recd.* 24/3/55.)

SOCIETY FOR THE STUDY OF DEVELOPMENT AND GROWTH. Dynamics of growth processes. A symposium of the Society. . . . Edited by E. J. Boell. Princeton, N.J. 1954. pp. vii + 304. ill. Princeton Univ. Pr. $7.50. (*Recd.* 18/3/55.)

LOCAL REPRESENTATIVES OF THE CHEMICAL SOCIETY

Aberdeen.	R. H. Thomson, Ph.D., F.R.I.C., Chemistry Department, The University, Old Aberdeen.
Australia.	Professor A. J. Birch, M.Sc., D.Phil., Department of Organic Chemistry, The University, Sydney, N.S.W., Australia.
Birmingham.	J. C. Tatlow, B.Sc., Ph.D., Department of Chemistry, The University, Edgbaston, Birmingham, 15.
Bristol.	P. Woodward, B.Sc., Ph.D., Chemistry Department, The University, Woodland Road, Bristol.
Cambridge.	R. N. Haszeldine, B.Sc., M.A., Ph.D., University Chemical Laboratory, Pembroke Street, Cambridge.
Canada.	W. D. McFarlane, M.A., Ph.D., The Laboratories, The Canadian Breweries Ltd., 496, Queen Street East, Toronto, 2, Canada.
Ceylon.	M. U. S. Saltanbawa, B.Sc., Ph.D., A.R.I.C., Department of Chemistry, The University, Colombo, Ceylon.
Edinburgh.	G. O. Aspinall, B.Sc., Ph.D., Chemistry Department, King's Buildings, West Mains Road, Edinburgh.
Exeter.	K. Schofield, B.Sc., Ph.D., Department of Chemistry, Washington Singer Laboratories, Prince of Wales' Road, Exeter.
Glasgow.	D. S. Payne, B.Sc., Ph.D., A.R.I.C. Chemistry Department, The University, Glasgow, W.2.
Hull.	G. W. Gray, B.Sc, Ph.D., Chemistry Department, The University, Hull.
India.	Professor T. R. Seshadri, M.A., Ph.D., F.R.I.C., Department of Chemistry, The University, Delhi, India.
Irish Republic.	D. O Tuama, M.Sc., Ph.D., F.I.C.I., Medical Research Council of Ireland, The Laboratories, Trinity College, Dublin.
Leeds.	E. Rothstein, Ph.D., D.Sc., A.R.C.S., Organic Chemistry Department, The University, Leeds, 2.
Liverpool.	A. K. Holliday, B.Sc., Ph.D., Department of Physical and Inorganic Chemistry, The University, Liverpool.
,,	D. W. Broad, Ph.D., A.R.I.C., Imperial Chemical Industries, Ltd., Research Department, Widnes Laboratory, Widnes.
Manchester.	G. R. Barker, B.Sc., Ph.D., Chemistry Department, The University, Manchester, 13.
,,	A. C. Farthing, M.A., B.Sc., Imperial Chemical Industries, Ltd., Hexagon House, Blackley, Manchester, 9.
Newcastle and Durham.	G. A. Swan, D.Sc., Ph.D., F.R.I.C., Department of Chemistry, King's College, Newcastle-on-Tyne, 1.
New Zealand.	Professor S. N. Slater, M.Sc., D.Phil., A.R.I.C., Chemistry Department, Victoria University College, Wellington, New Zealand.
Northern Ireland.	R. G. R. Bacon, PhD., A.R.C.S., Chemistry Department, Queen's University, Belfast.
North Wales.	J. E. McKail, Ph.D., Department of Chemistry, University College of North Wales, Bangor.
Nottingham.	C. C. Addison, D.Sc., Ph.D., F.R.I.C., Chemistry Department, The University, University Park, Nottingham.
Oxford.	L. A. K. Staveley, M.A., Inorganic Chemistry Laboratory, South Parks Road, Oxford.
Pakistan.	M. I. D. Chughtai, M.Sc.Tech., Ph.D., A.R.I.C., Panjab University Institute of Chemistry, The Mall, Lahore, Pakistan.
St. Andrews and Dundee.	C. Horrex, M.A., Ph.D., Chemistry Department, The University, St. Andrews.
Sheffield.	H. J. V. Tyrrell, M.A., B.Sc., Chemistry Department, The University, Sheffield, 10.
South Africa.	Professor W. Pugh, Ph.D., B.Sc., F.R.I.C., Chemistry Department, University of Cape Town, Rondebosch, S. Africa.
Southampton.	N. B. Chapman, M.A., Ph.D., Department of Chemistry, The University, Southampton.
South Wales.	K. W. Sykes, M.A., B.Sc., D.Phil., Department of Chemistry, University College, Singleton Park, Swansea.

PROCEEDINGS
OF THE
CHEMICAL SOCIETY

SCIENTIFIC MEETINGS DURING JULY, 1955

BRISTOL.

Tuesday, July 19th, 1955, at 7 p.m.

Lecture, "Organo-metallic Compounds of the Acetylenic Type," by Professor Dr. H. Hartmann. Joint Meeting with the Royal Institute of Chemistry, the Society of Chemical Industry, and the University Chemical Society, to be held in the Department of Chemistry, The University, Woodland Road.

EXETER.

Wednesday, July 13th to Friday, July 15th, 1955.

Official Meeting and Symposium on "Recent Work on Naturally Occurring Nitrogen Heterocyclic Compounds." Full details have been circulated.

OFFICIAL ANNOUNCEMENTS

DEATHS.

The Council regrets to announce the deaths of the following Fellows :

	Elected.	Died.
Reginald Gordon Halstead (London, E.6)	May 3rd, 1900.	March 9th, 1955.
Thomas Mackenzie (Inverness)	Feb. 16th, 1899.	Feb. 22nd, 1952.
William Pugh (Rondebosch)	Feb. 16th, 1933.	March 12th, 1955.
Walter William Reed (Norwich)	June 16th, 1910.	March 19th, 1955.
Gwyn Williams (London, S.W.1) (C. 1950—1)...	Dec. 3rd, 1925.	April 5th, 1955.

CONGRATULATIONS.

The President has conveyed the congratulations of the Society to the following Fellows who completed 60 years of Fellowship on May 16th :

Harold Allden Auden (Burton-on-Trent).
John McGlashan (East London, S. Africa).
George Elliot Shaw (Tonbridge).

and to the following who completed 50 years of Fellowship on May 4th :

Francis George Belton (Birmingham).
Horace Finnemore (Sydney).
Ernest Robert Marle (Shepperton).
Alfons O'Farrelly (Dublin).
Arthur Walsh Titherley (Winchester).

ACKNOWLEDGMENTS.

Acknowledgment is made of a gift of photographs and correspondence, formerly belonging to the later Henry Edward Armstrong, and presented to the Society by Dr. J. Vargas Eyre.

Gifts of the Society's publications from Mr. D. H. Laney and Mr. A. Marshall are also acknowledged.

ELECTION OF NEW FELLOWS.

The following 160 candidates were elected to the Fellowship on May 5th, 1955 :

John Brian Ainscough.
Ramaswami Iyer Anantaraman.
William Robert Brinley Arthur.
John Stanley Ashbrook.
Friederike Fedora Auslander.
Bernard John Aylett.
Arthur James Banister.
Irene Bates.
William Batey.
Jean Margaret Batstone.
Leslie Batt.
Alfredo Behrens.
Merton Ian Behrman.
Myron Lee Bender.
Samuel Berkovic.
Francis van Massy Bevan.
Kathleen Molly Bonneywell.
George Murray Burnett.
Michael Stephen Burton.
Beverley Carss.
Donald Athelstan Casson.
Shih Chang.
Fa-Ching Chen.
Clifford Brian Clarke.
Roger Christopher Clarke.
Jeremy Austin Grey Collier.
Joseph Charles Collins, jun.
Ruth Margaret Collins.
Donald Joseph Coplin.
Michael Norman Court.
Brian Richard Cowley.
Jeffery Cragg.
Derrick Henry Dorken.
Thomas Joseph Doughty.
Jeanne Monica Dunn.
William David Emmons.
Arthur Thomas Fenlon.
T. Lloyd Fletcher.
Martin Graham Ford.
Jeremiah Patrick Freeman.
Douglas James Fry.
Peter William Grover George.
John Frederick Gibson.
Martin Stewart Gibson.
Stanley William Gilks.
Arthur Harvey Goldkamp.
Mervyn Stuart Grant.
John Wilson Green.

William John Green.
Louise Elizabeth Greig.
Roy David Guthrie.
David Hall.
James Baillie Headridge.
Amy Edith Jean Herbert.
Richard Beautyman Heslop.
Howard Dudley Crile Hill.
Ronald Hill.
Bruno Hofer.
Donald Holroyd.
William Joseph Houlihan.
Bernard Stuart Hurlbert.
Hans Herloff Inhoffen.
David Arthur John Ives.
David Stewart Jenkinson.
Robert Edwin Jewell.
David Neville Jones.
Michael John Jones.
Robert Hipwell Knight.
Frantisek Krejci.
Harry Davis Law.
Nathan Lewis.
Stanley Edward Mervyn Richard Livingstone.
Lawrence Lloyd.
Peter Frederick Lloyd.
Kenneth Alan Keeler Lott.
George William Loveday.
Raymond Marshall.
Virgil Edison Matthews.
Emil J. Maxion.
Jaysukhlal Ranchoddas Merchant.
Barbara Lily Meyer.
Charles James Miller.
John Dudley Morris.
George Anderson Morrison.
Wesley Brock Neely.
Kay LeRoi Nelson.
Philip Howard James Newnham.
Douglas Lindley Newton.
Barry Nicholls.
Charles Joseph Norton.
John Thomas Ouderkirk.
Joseph Hayes Paden.
Frederick Granville Page.
Joyce Margaret Penny.
Ivy Elizabeth Perry.
Leslie Phoenix.
Thomas Arthur Pinfold.
Jack Leon Pinkus.
Frank Donald Popp.
Chrysoula Caliope A. Prevedorou.
William Pringle.
Robert Henry Ramsden.
Douglas Irving Relyea.
Elizabeth Rhodes.
Willis Dale Richey.
Raymond Frank Robbins.
Vernon Rogers.
George Ryback.
Lawrence George Albert Sallabanks.
Pentti Antero Salomaa.
Bryan Scales.
Haruo Shingu.
James Vincent Silverton.
David James Silvester.
James George Sime.
Benjamin A. Simmons.
Edward Alexander Simpson.
Nigel Arthur Smart.
Hamilton Smith.
Leonard Christopher Smith.
Richard Frederick Smith.
Lloyd Earle Smythe.
Richard Allen Sneen.
Michael Alfred Sparks.
Harold Spedding.
John Spillane.
James Edward Stephenson.
Ian Donald Ross Stevens.
John Stewart.
Melville Harold Bateman Stiddard.
Robert David Stolow.
Frank Sidney Stone.
Yusuke Sumiki.
William Terrance Swanton.
Richard Francis Sweeney.
Philip John Taylor.
Raghunath Singh Thakur.
David Arthur Thomas.
James Cecil Tomkinson.
Roy Charles Bleay Tomlinson.
Mary Rosaleen Truter.
Shivendra Varma.
Ernst J. Vogel.
Ian Gordon Wallace.
David Albert Mercer Watkins.
David Harris Watson.
Kenneth Franklin Watterson.
Alan John Maurice Wenham.
Alan Duane Westland.
Michael Arthur Wheelans.
Michael Anthony Whitehead.
Kenneth Crerar Bayne Wilkie.
Alan Williams.
Ronald William James Williams.
Joseph Dodman Wilson.
David Brian Wootton.
Yao Hua Wu.
Hans Wynberg.
Thomas Alan Yarwood.
Roy William Yorke.

LOCAL REPRESENTATIVES.

The following appointments have been made :

Professor J. K. N. Jones (Canada) in place of Dr. W. D. McFarlane.
Dr. G. O. Aspinall (Edinburgh) in place of Dr. T. R. Bolam.
Mr. A. C. Farthing (Manchester) in place of Dr. M. A. T. Rogers.
Professor F. L. Warren (S. Africa) in place of the late Professor W. Pugh.

The President has conveyed the thanks of the Council to the retiring Local Representatives for their services to the Society.

LIBRARY.

To permit extensive refurnishing and reorganisation, the Library will be closed from Monday, July 4th to Monday, August 15th. The photocopy service will be suspended from June 10th. All books and periodicals should be returned to the Library not later than Monday, June 27th.

MINUTES OF SCIENTIFIC MEETINGS

Minutes of a

SCIENTIFIC MEETING

held in the Lecture Theatre of the Royal Institution, on Thursday, March 31st, 1955, at 11 a.m.

The President, PROFESSOR W. WARDLAW, C.B.E., D.Sc., F.R.I.C., was in the Chair.

MINUTES.

The Minutes of the Scientific Meeting held at Burlington House on March 17th were read, and were confirmed and signed.

FORMAL ADMISSION OF FELLOWS.

The following were admitted Fellows of the Society : K. Linderstrøm-Lang, Dagoberto E. Weisbach, S. A. Spearing, P. Woodward, A. K. Chatterjee, B. N. Chakravarti, E. A. Raynham, N. E. Williams, Gordon S. Harris, A. C. Farthing, R. B. Gauntlett, R. J. Hill, E. C. Porter, H. S. D. Simpson, P. R. Thomas, John Boulton, Pauline M. Everitt, W. L. F. Armarego, R. Thompson, P. Boulanger.

LECTURE.

After a brief introduction the President called upon Dr. G. Randers to deliver the lecture entitled "The Outlook for Industrial Atomic Energy in Europe." At the conclusion of the lecture, a vote of thanks to Dr. Randers, proposed by the President, was carried with acclamation.

LIST OF APPLICATIONS FOR FELLOWSHIP

(*Fellows wishing to lodge objections to the election of these candidates should communicate with the Honorary Secretaries within ten days of the date of publication of the* Journal *for May*, 1955. *Such objections will be treated as confidential. The forms of application are available in the Library.*)

Arnheim, Joanne, B.S. (Queen's Coll. Flushing). American. 219, Noyes Laboratory, University of Illinois, Urbana, Illinois, U.S.A. Student. *Signed by:* D. Y. Curtin, R. E. Lyle, D. F. Morrow.

Bensley, Beldon, B.Sc. and Ph.D. (Dunelm), A.R.I.C. British. 1, St. Aidans Crescent, Billingham, Co. Durham. National Serviceman. *Signed by:* W. K. R. Musgrave, G. Kohnstam.

Bosanquet, Percival Alfred, M.B.E., B.Sc. (Bris.). British. 253, Coulsdon Road, Old Coulsdon, Surrey. Chemistry Teacher at The Polytechnic, Regent Street, W.1. *Signed by:* W. Davey, B. E. Dawson.

Croatto, Ugo, Dr.Chem. (Padova). Italian. Istituto Chimica Generale, Universita di Padova, Via L. Loredan, N.4, Padova, Italy. Professor of Inorganic Chemistry. *Signed by:* L. Musajo, G. Tappi.

Davis, Walter, B.Sc. and Ph.D. (Lond.), A.R.C.S. British. 12, Brookfield Park, London, N.W.5. Organic Chemist at the Royal Cancer Hospital. *Signed by:* R. C. Bray, W. C. J. Ross.

De Bruyn, Paulus, D. ès Sc. (Paris). Dutch. Petit Saussay, Ballancourt, Seine et Oise, France. *Signed by:* J. W. Cook, James D. Loudon.

Edwards, Anthony John. British. 107, Hurst Road, Sidcup, Kent. Undergraduate at Trinity College, Oxford. *Signed by:* L. A. K. Staveley, H. Irving.

Egerton, Michael John, B.Sc. (Bris.). British. 131, Linden Road, Gloucester. National Serviceman. *Signed by:* T. Malkin, T. H. Bevan.

Emmott, Paul, B.Sc. (Lond.). British. 82, Princess Street, Nelson, Lancs. Research Student at Burnley Municipal College. *Signed by:* J. R. Hartley, A. E. Wales.

Falconer, Gordon James, B.Sc. (Dunelm). British. 327, Milnrow Road, Rochdale, Lancs. Industrial Chemist. *Signed by:* E. E. Aynsley, R. Raper.

Goldstein, Bernard, B.A. (Penn.). American. 6538, Cutler Street, Philadelphia, 26, Pennsylvania, U.S.A. Graduate Student at Rutgers University. *Signed by:* J. S. Showell, W. T. Holfeld.

Grimes, Alan James, B.Sc. (Lond.). British. 8A, Angel Corner Parade, Edmonton, London, N.18. Student. *Signed by:* C. J. W. Brooks, P. de Mayo.

Hill, Betty Eunice, B.Sc. (Leeds). British. "Kilchattan," Kirkstall Lane, Leeds, 6. Research Student. *Signed by:* E. Rothstein, B. Lythgoe.

Hoult, Timothy George, B.A (Oxon) British. No. 2, Officers' Mess, R.A.F., Hullavington, Wiltshire. National Serviceman. *Signed by:* S. G. P. Plant, R. M. Acheson.

Johnson, Ronald Mark. British. 17, Frankham House, Frankham Street, Deptford, London, S.E.8. Technical Research Laboratory Assistant at Crosse and Blackwell, Ltd. *Signed by:* D. J. G. Ives, J. W. Ladbury.

Knight, Norman Charles, B.Sc. (Lond.), A.R.I.C. British. Station House, Station Road, Bulwell, Nottingham. Analytical Chemist. *Signed by:* E. Tittensor, G. F. Hall.

Knights, Brian Arthur. British. 74, North Road, Hertford, Herts. Student. *Signed by:* M. J. S. Dewar, W. J. Hickinbottom.

Mackenzie, John Douglas, B.Sc. and Ph.D. (Lond.), D.I.C., A.R.I.C. British. Forrestal Research Centre, Princeton University, Princeton, New Jersey, U.S.A. Research Fellow. *Signed by:* D. J. G. Ives, R. W. Pittman.

Nobles, William Lewis, M.S. (Mississippi), Ph.D. (Kansas). American. Box 611, University of Mississippi, University, Mississippi. Associate Professor of Pharmaceutical Chemistry. *Signed by:* J. H. Burckhalter, W. E. McEwen.

Roberts, John James, B.Sc. and Ph.D. (Lond.). British. 2, Herbert Road, Wimbledon, London, S.W.19. Research Chemist. *Signed by:* G. P. Warwick, W. C. J. Ross.

Rodger, Mitchell Nicolson. British. 5, Orchy Avenue, Stamperland, Clarkston, Renfrewshire. Student. *Signed by:* M. F. Grundon, J. C. D. Brand.

Shepherd, Brian Discombe, B.Sc. and Ph.D. (Lond.). British. 94, Albert Road, Ilford, Essex. Research Chemist. *Signed by:* R. Slack, D. D. Libman.

Shorthouse, Barry Owen. British. 53, Pear Tree Avenue, Bitterne, Southampton. Assistant Research Chemist. *Signed by:* N. B. Chapman, G. W. A. Fowles.

Spada, Alberto. Istituto Chimica Farmaceutica Universita di Modena, Italy. Director. *Signed by:* G. Tappi, L. Musajo.

Warder, John Frederick, B.Sc. (Lond.). British. The Cottage, High Easter, Nr. Chelmsford, Essex. Research Student. *Signed by:* C. M. French, D. Feakins.

Williams, Arthur Alan, B.Sc. (Lond.). British. The Frythe, Welwyn, Herts. Research Chemist. *Signed by:* J. Chatt, G. A. Gamlen, L. M. Venanzi.

Winser, Alan David, B.Sc. (Lond.), A.R.I.C. British. 26, St. George's Avenue, Grays, Essex. Research Chemist at Thames Board Mills, Ltd., Purfleet. *Signed by:* F. L. Allen, J. R. Young.

Wittekind, Raymond Richard, B.S. (Polytech. Inst. of Brooklyn), A.M. (Columbia). American. 138—13 97 Avenue, Jamaica 35, New York, U.S.A. Student at Columbia University, New York. *Signed by:* G. Stork, Y. W. Chang.

UNDER SPECIAL PROVISION APPERTAINING TO CANDIDATES RESIDENT ABROAD.

Crawford, Robert James, M.Sc. (Alberta). Canadian. 606, W. Ohio Street, Urbana, Illinois. Graduate Student at University of Illinois. *Signed by:* D. Y. Curtin.

Matt, Joseph, B.S. (Pa.), Ph.D. (Purdue). American. Research Department, Virginia-Carolina Chemical Corporation, Richmond, Virginia, U.S.A. Research Chemist. *Signed by:* E. Rapkin.

Müller, Paul, Dr.Phil. (Basle). Swiss. Glaserbergstrasse 78, Basle, Switzerland. Industrial Chemist with J. R. Geigy and Co. *Signed by:* W. Wardlaw.

Pascual, Octavius Santos, M.S. (Louisiana). Filipino. Box 5324, Louisiana State University, Baton Rouge 3, Louisiana, U.S.A. Graduate Student. *Signed by:* J. L. E. Erickson.

Pathak, Sahdeo Prasad, M.Sc.Tech. (Banaras Hindu Univ.), Ph.D. (Liv.). Indian. College of Technology, Banaras Hindu University, Banaras, India. Reader in Industrial Chemistry. *Signed by:* T. P. Hilditch.

PAPERS ACCEPTED

(List of Papers accepted between March 24th and April 22nd, 1955, for publication in the *Journal*.)

Numbers quoted are "Reprint Order Numbers." Reprints may be ordered from the list below, or from the published *Journal* (January, 1954, onwards). Orders must be sent to the General Secretary accompanied by a remittance for 5*s*. for each reprint or by the appropriate number of reprint vouchers.

5350. "Pristimerin. Part I." By R. C. SHAH, A. B. KULKARNI, and V. M. THAKOR.
5674. "The solubilities and heats of crystallisation of sucrose and methyl α-D-glucoside in aqueous solution." By W. S. WISE and E. B. NICHOLSON.
5773. "Liquid-phase reactions at high pressure. Part IX. The polymerisation of some 1 : 2-disubstituted ethylenes." By W. A. HOLMES-WALKER and K. E. WEALE.
5995. "Studies in the pyrolysis of organic bromides. Part IV. The pyrolysis of *sec.*-butyl bromide." By ALLAN MACCOLL and P. J. THOMAS.
5996. "Studies in the pyrolysis of organic bromides. Part V. The pyrolysis of *cyclo*hexyl bromide." By J. H. S. GREEN and ALLAN MACCOLL.
5997. "Studies in the pyrolysis of organic bromides. Part VI. The pyrolysis of *tert.*-butyl bromide." By G. D. HARDEN and ALLAN MACCOLL.
6012. "Studies on organic fluorine compounds. Part IV. The synthesis of esters of fluoro-oxaloacetic and of fluoropyruvic acid." By I. BLANK, J. MAGER, and ERNST D. BERGMANN.
6037. "The thermal decomposition of silver nitrite." By T. M. OZA, V. T. OZA, and R. H. THAKER.
6041. "The action of ammonia on 4-alkylidene-2-thiothiazolid-5-ones." By F. P. DOYLE, D. O. HOLLAND, and J. H. C. NAYLER.
6049. "Perimidine dyes and intermediates." By R. A. JEFFREYS.
6063. "Organosilicon compounds. Part XIV. The reaction between trisubstituted silanes and silver perchlorate." By C. EABORN.
6064. "Electronic spectra, hyperconjugation, and the Baker–Nathan effect." By A. BURAWOY and E. SPINNER.
6072. "Oxidation of polyhalogeno-compounds. Part I. Photochemical oxidation of certain fluoroalkanes." By W. C. FRANCIS and R. N. HASZELDINE.
6088. "Superoxide ions in commercial sodium peroxide." By PHILIP GEORGE.
6091. "The selective elution of metals adsorbed on cation-exchange resins by organic solvents. Part I." By N. F. KEMBER, PATRICIA J. MACDONALD, and R. A. WELLS.
6094. "The conductometric evaluation of the ionisation functions of the monohalogenoacetic acids." By D. J. G. IVES and J. H. PRYOR.
6095. "β-Aroylpropionic acids. Part V. The synthesis of β-aroyl-α-methylpropionic acids, and their conversion into polynuclear compounds." By F. G. BADDAR, H. A. FAHIM, and ABDALLAH M. FLEIFEL.
6112. "Immunopolysaccharides. Part V. Structure of a modified *Betacoccus arabinosaceous* dextran." By S. A. BARKER, E. J. BOURNE, A. E. JAMES, W. B. NEELY, and M. STACEY.
6115. "The catalytic hydrogenation of ethylene at a nickel surface. Part I. The chemisorption of ethylene." By G. I. JENKINS and SIR ERIC RIDEAL.
6116. "The catalytic hydrogenation of ethylene at a nickel surface. Part II. The reaction mechanism." By G. I. JENKINS and SIR ERIC RIDEAL.
6119. "The synthesis of methyl ethers of mannuronic and glucuronic acid, and their reaction with periodate." By R. A. EDINGTON, E. L. HIRST, and ELIZABETH E. PERCIVAL.
6129. "Cinnolines. Part XXXIV. 5-, 6-, and 7-Hydroxy- and 5-, 6-, and 7-aminocinnolines." By A. R. OSBORN and K. SCHOFIELD.

6130. "Polyazabicyclic compounds. Part I. Preliminary experiments on the Bischler and the Bamberger synthesis of benzo-1 : 2 : 4-triazines." By R. A. ABRAMOVITCH and K. SCHOFIELD.

6139. "Studies in the steroid series. Part LXIX. Bromination of 11-oxo-5α-steroids." By H. B. HENBEST, E. R. H. JONES, A. A. WAGLAND, and T. I. WRIGLEY.

6140. "A study of the diffusion in water of potassium laurate, by the Gouy method." By N. BRUDNEY and L. SAUNDERS.

6141. "An attempt to simulate the biogenesis of strychnine. Part I. Experiments with 4-2′-aminoethylpyridine." By A. R. KATRITZKY.

6143. "The hydrothermal chemistry of silicates. Part VI. A lamellar habit in synthetic felspar." By J. A. GARD, R. M. BARRER, and J. BAYNHAM.

6144. "The synthesis of compounds with potential anti-folic acid activity. Part VI. Polyaza-1 : 2-benzanthracene derivatives." By T. S. OSDENE and G. M. TIMMIS.

6147. "The hydrolysis of acetamide and acethydrazide in hydrochloric acid of various strengths." By J. T. EDWARD, H. P. HUTCHISON, and S. C. R. MEACOCK.

6153. "Potential tumour inhibitors. Esters of 4-di-(2-hydroxyethyl)aminopyridine and quaternary derivatives of 2 : 3-dihydroglyoxalino[1 : 2-*a*]pyridine." By F. C. COPP and G. M. TIMMIS.

6155. "α- and β-Methyl L-fucofuranosides." By WINIFRED M. WATKINS.

6158. "Properties of ion-exchange resins in relation to their structure. Part VII. Cation-exchange equilibria on sulphonated polystyrene resins of varying degrees of cross-linking." By D. REICHENBERG and D. J. MCCAULEY.

6160. "*p*-Hydroxybenzoate groups in the lignin of Aspen (*Populus tremula*)." By D. C. C. SMITH.

6163. "An attempt to simulate the biogenesis of strychnine. Part II. Preparation and transformations of 3-(2-4′-pyridylacetamidoethyl)indole." By A. R. KATRITZKY.

6168. "Anodic syntheses. Part IV. The use of acetylenic components. A new synthesis of oleic acid." By B. W. BAKER, R. P. LINSTEAD, and B. C. L. WEEDON.

6169. "The cyclodehydration of anils. Part I. Kinetics of cyclodehydration of 4-anilino- and 4-*p*-toluidino-pent-3-en-2-one in sulphuric acid." By T. G. BONNER, M. P. THORNE, and J. M. WILKINS.

6170. "The cyclodehydration of anils. Part II. The hydrogen isotope effect in the cyclodehydration of 4-anilinopent-3-en-2-one." By T. G. BONNER and J. M. WILKINS.

6171. "Hydroxybenzotropones. Part I. Synthesis of a dimethoxybenz*ocyclo*hepta-1 : 4-diene-3 : 7-dione." By A. J. S. SORRIE and R. H. THOMSON.

6172. "Hydroxybenzotropones. Part II. The isomeric 1 : 2 : 3 : 4-tetrahydro-2 : 3-methylene-1 : 4-dioxonaphthalenes." By A. J. S. SORRIE and R. H. THOMSON.

6173. "Hydroxybenzotropones. Part III. Synthesis of a hydroxydimethoxydibenzotropone." By A. J. S. SORRIE and R. H. THOMSON.

6177. "The vapour pressures of nitric acid solutions. Part I. New azeotropes in the water–dinitrogen pentoxide system." By L. LLOYD and F. A. H. WYATT.

6179. "The preparation of [^{14}C]ethylenediamine dihydrochloride from [1-^{14}C]ethanol." By D. S. POPPLEWELL and R. G. WILKINS.

6180. "The mechanism of a chromate process for the separation of the lanthanons and yttrium." By R. W. HALL.

6186. "Triterpenoids. Part XXXVII. The constitution of taraxerol." By J. M. BEATON, F. S. SPRING, ROBERT STEVENSON, and J. L. STEWART.

6187. "The viscosity of the vapours of *n*-octane and 2 : 2 : 4-trimethylpentane." By G. A. MCD. CUMMINGS and J. C. MCCOUBREY.

6188. "Collision diameters of flexible hydrocarbon molecules in the vapour phase." By G. A. MCD. CUMMINGS and A. R. UBBELOHDE.

6189. "Syntheses of 8-substituted quinolines with amide groups in the side chain." By M. NEEMAN.

6190. "Alkaloids of Australian *Strychnos* species. Part II. The constitution of strychnospermine and spermostrychnine." By F. A. L. ANET and SIR ROBERT ROBINSON.

6192. "ω-Halogenomethyl-pyridines, -quinolines, and -*iso*quinolines. Part V. Preparation of compounds related to 1 : 2-di-2'-quinolylethane." By D. Ll. Hammick, C. N. Lammiman, E. D. Morgan, and A. M. Roe.

6194. "Alicyclic glycols. Part XIII. 1 : 2-Bishydroxymethyl*cyclo*pentane." By L. N. Owen and A. G. Peto.

6195. "The chemistry of fungi. Part XXV. Oosporein, a metabolite of *Chaetomium aureum* Chivers." By G. Lloyd, Alexander Robertson, G. B. Sankey, and W. B. Whalley.

6196. "Usnic acid. Part XI. A synthesis of 7-acetyl-4 : 6-dihydroxy-3 : 5-dimethylcoumaran-2-one." By F. M. Dean and Alexander Robertson.

6200. "The infrared spectra of some esters, nitriles, and ester-nitriles." By D. G. I. Felton and S. F. D. Orr.

6202. "The constitution of some 3-methyl*cyclo*hex-2-enone dimers." By W. A. Ayer and W. I. Taylor.

6222. "Some physical properties of nitryl fluoride." By G. Hetherington and P. L. Robinson.

6227. "1 : 2-Dihydro-2 : 2-dimethylquinazolines. The condensation of acetone with anthranilamide derivatives." By H. C. Carrington.

6228. "Liquid metals. Part II. The surface tension of liquid sodium : the drop-volume technique." By C. C. Addison, W. E. Addison, D. H. Kerridge, and J. Lewis.

6236. "The heat of formation of nickel carbonyl." By K. W. Sykes and S. C. Townshend.

6238. "The direct interaction of *N*-bromosuccinimide and benzoyl peroxide." By M. C. Ford.

6239. "6-Methoxy-2-naphthaldehyde." By R. P. Gandhi, V. S. Gaind, and S. M. Mukherji.

6240. "The crystal structure of methylene-blue." By J. O. Warwicker.

6279. "Synthesis of (±)-massoialactone." By L. Crombie.

ADDITIONS TO THE LIBRARY

I. *Donations*

A. *Books.*

Bracken, A. The chemistry of the micro-organisms. London **1955**. pp. vii + **343**. ill. 30*s*. (*Recd.* **14/4/55.**)

From the Publishers : Sir Isaac Pitman & Sons, Ltd.

B. *Pamphlets.*

Hedvall, J. A. Principal results about the reactivity of solids. Rio de Janeiro **1954**. pp. **11**. ill.

II. *By purchase*

Ahrens, L. H. Quantitative spectrochemical analysis of silicates. London **1954**. pp. **122**. ill. Pergamon Pr. 25*s*. (*Recd.* **26/3/55.**)

Bacq, Z. M., and Alexander, P. Fundamentals of radiobiology. London **1955**. pp. xii + **389**. ill. Butterworths Scientific Publications. 40*s*. (*Recd.* **26/3/55.**)

Berry, A. J. From classical to modern chemistry. Cambridge **1954**. pp. xii + **251**. Cambridge Univ. Pr. 25*s*. (*Recd.* **26/3/55.**)

Bosworth, R. C. L. Heat transfer phenomena; the flow of heat in physical systems. Sydney **1952**. pp. xii + **211**. ill. Associated General Publications Pty. Ltd. 42*s*. (*Recd.* **26/3/55.**)

Bovey, F. A. [and others]. Emulsion polymerization. New York **1955**. pp. xii + **445**. ill. (High Polymers, Vol. 9.) Interscience. £5. (*Recd.* **4/4/55.**)

British Medical Bulletin. Vol. **10**, No. **3**. Chromatography. London **1954**. Medical Dept., The British Council. 15*s*. (*Recd.* **4/4/55.**)

Brügel, W. Einführung in die Ultrarotspektroskopie. Darmstadt **1954**. pp. xii + **366**. ill. Steinkopff. *DM* **49**. (*Recd.* **26/3/55.**)

Colowick, S. [and others]. *Editors.* Glutathione. Proceedings of the symposium held . . . **1953**. New York **1954**. pp. x + **341**. ill. Academic Pr. 60*s*. (*Recd.* **26/3/55.**)

Cramer, F. Einschlussverbindungen. Berlin **1954**. pp. iv + **115**. ill. Springer. *DM* **14.80**. (*Recd.* **4/4/55.**)

DELAHAY, P. New instrumental methods in electrochemistry. New York **1954**. pp. xvii + **437**. ill. Interscience. **$11.50**. (*Recd.* **26/3/55**.)

EPHRAIM, F. Inorganic chemistry. **6**th edition. By P. C. L. THORNE and E. R. ROBERTS. London **1954**. pp. xii + **956**. ill. Oliver & Boyd. **35***s*. (*Recd.* **26/3/55**.)

EVERS, N., and SMITH, W. The analysis of drugs and chemicals. London **1955**. pp. x + **546**. Griffin. **60***s*. (*Recd.* **26/3/55**.)

GLASCOCK, R. F. Isotopic gas analysis for biochemists. New York **1954**. pp. viii + **247**. ill. Academic Pr. **$5.50**. (*Recd.* **26/3/55**.)

GOLOWA, O. P., and IWANOW, W. I. Über das Molekulargewicht der Zellulose. Berlin **1953**. pp. vii + **91**. ill. Akademie-Verlag. **15***s*. (*Recd.* **29/3/55**.)

GREENBERG, D. M., *Editor*. Chemical pathways of metabolism. **2** vols. New York **1954**. pp. x + **460**; x + **383**. ill. Academic Pr. **$11** (Vol. **1**); **$7.50** (Vol. **2**). (*Recd.* **30/3/55**.)

GROGGINS, P. H., *Editor*. Unit processes in organic synthesis. **4**th edition. London **1953**. pp. xiii + **937**. ill. McGraw-Hill. **90***s*. (*Recd.* **26/3/55**.)

GUGGENHEIM, E. A., and PRUE, J. E. Physicochemical calculations. Amsterdam **1955**. pp. xii + **491**. North-Holland Pub. Co. **53***s*. (*Recd.* **1/4/55**.)

HOLLINGSHEAD, R. G. W. Oxine and its derivatives. Vol. **1**, Oxine—Part **1**; Vol. **2**, Oxine—Part **2**. London **1954**. pp. x + **322**; **616**. Butterworths Scientific Publications. **84***s*. (*Recd.* **26/3/55**.)

KENT, P. W., and WHITEHOUSE, M. W. Biochemistry of the aminosugars. London **1955**. pp. ix + **311**. ill. Butterworths Scientific Publications. **40***s*. (*Recd.* **26/3/55**.)

MATZ, G. Die Kristallisation in der Verfahrenstechnik. Berlin **1954**. pp. viii + **194**. ill. Springer. *DM* **19.50**. (*Recd.* **26/3/55**.)

MEE, A. J. Physical chemistry. **5**th edition. London **1954**. pp. xviii + **726**. ill. (*Recd.* **26/3/55**.)

MILTON, R. F., and WATERS, W. A. Methods of quantitative micro-analysis. **2**nd edition. London **1955**. pp. xi + **742**. ill. Edward Arnold. **70***s*. (*Recd.* **26/3/55**.)

MIZUSHIMA, SAN-ICHIRO. Structure of molecules and internal rotation. New York **1954**. pp. x + **244**. ill. Academic Pr. **48***s*. (*Recd.* **26/3/55**.)

MOLLOY, E., and CARR, E., *Editors*. Catalysts, special compounds, and chemical resistant materials. London **1955**. pp. x + **222**. ill. Newnes. **21***s*. (*Recd.* **26/3/55**.)

PITZER, K. S. Quantum chemistry. London **1953**. pp. x + **529**. ill. Constable. **63***s*. (*Recd.* **26/3/55**.)

RAPHAEL, R. A. Acetylenic compounds in organic synthesis. London **1955**. pp. xii + **219**. Butterworths Scientific Publications. **30***s*. (*Recd.* **26/3/55**.)

ROBINSON, R. A., and STOKES, R. H. Electrolyte solutions; the measurement and interpretation of conductance, chemical potential and diffusion in solutions of simple electrolytes. London **1955**. pp. xiii + **512**. ill. Butterworths Scientific Publications. **56***s*. (*Recd.* **26/3/55**.)

RUBIN, B. A., and ARZICHOWSKAJA, E. W. Biochemische Charakteristik der Widerstandsfähigkeit der Pflanzen gegenüber Mikroorganismen. Berlin **1953**. pp. **87**. ill. Akademie-Verlag. **14***s*. **6***d*. (*Recd.* **25/3/55**.)

TRAPNELL, B. M. W. Chemisorption. London **1955**. pp. viii + **265**. ill. Butterworths Scientific Publications. **35***s*. (*Recd.* **26/3/55**.)

WHITE, A. [and others]. Principles of biochemistry. New York **1954**. pp. xiii + **1117**. ill. McGraw-Hill. **$15**. (*Recd.* **26/3/55**.)

LOCAL REPRESENTATIVES OF THE CHEMICAL SOCIETY

Aberdeen.	R. H. Thomson, Ph.D., F.R.I.C., Chemistry Department, The University, Old Aberdeen.
Australia.	Professor A. J. Birch, M.Sc., D.Phil., Department of Organic Chemistry, The University, Sydney, N.S.W., Australia.
Birmingham.	J. C. Tatlow, B.Sc., Ph.D., Department of Chemistry, The University, Edgbaston, Birmingham, 15.
Bristol.	P. Woodward, B.Sc., Ph.D., Chemistry Department, The University, Woodland Road, Bristol.
Cambridge.	R. N. Haszeldine, B.Sc., M.A., Ph.D., University Chemical Laboratory, Pembroke Street, Cambridge.
Canada.	Professor J. K. N. Jones, M.Sc., Ph.D., A.R.I.C., Queen's University, Kingston, Ontario.
Ceylon.	M. U. S. Sultanbawa, B.Sc., Ph.D., A.R.I.C., Department of Chemistry, The University, Colombo, Ceylon.
Edinburgh.	G. O. Aspinall, B.Sc., Ph.D., Chemistry Department, King's Buildings, West Mains Road, Edinburgh.
Exeter.	K. Schofield, B.Sc., Ph.D., F.R.I.C., Department of Chemistry, Washington Singer Laboratories, Prince of Wales' Road, Exeter.
Glasgow.	D. S. Payne, B.Sc., Ph.D., A.R.I.C. Chemistry Department, The University, Glasgow, W.2.
Hull.	G. W. Gray, B.Sc, Ph.D., Chemistry Department, The University, Hull.
India.	Professor T. R. Seshadri, M.A., Ph.D., F.R.I.C., Department of Chemistry, The University, Delhi, India.
Irish Republic.	D. O Tuama, M.Sc., Ph.D., F.I.C.I., Medical Research Council of Ireland, The Laboratories, Trinity College, Dublin.
Leeds.	E. Rothstein, Ph.D., D.Sc., A.R.C.S., Organic Chemistry Department, The University, Leeds, 2.
Liverpool.	A. K. Holliday, B.Sc., Ph.D., Department of Physical and Inorganic Chemistry, The University, Liverpool.
,,	D. W. Broad, Ph.D., A.R.I.C., Imperial Chemical Industries, Ltd., Research Department, Widnes Laboratory, Widnes.
Manchester.	G. R. Barker, B.Sc., Ph.D., Chemistry Department, The University, Manchester, 13.
,,	A. C. Farthing, M.A., B.Sc., Imperial Chemical Industries, Ltd., Hexagon House, Blackley, Manchester, 9.
Newcastle and Durham.	G. A. Swan, D.Sc., Ph.D., F.R.I.C., Department of Chemistry, King's College, Newcastle-on-Tyne, 1.
New Zealand.	Professor S. N. Slater, M.Sc., D.Phil., A.R.I.C., Chemistry Department, Victoria University College, Wellington, New Zealand.
Northern Ireland.	R. G. R. Bacon, PhD., A.R.C.S., Chemistry Department, Queen's University, Belfast.
North Wales.	J. E. McKail, Ph.D., Department of Chemistry, University College of North Wales, Bangor.
Nottingham.	C. C. Addison, D.Sc., Ph.D., F.R.I.C., Chemistry Department, The University, University Park, Nottingham.
Oxford.	L. A. K. Staveley, M.A., Inorganic Chemistry Laboratory, South Parks Road, Oxford.
Pakistan.	M. I. D. Chughtai, M.Sc.Tech., Ph.D., A.R.I.C., Punjab University Institute of Chemistry, The Mall, Lahore, Pakistan.
St. Andrews and Dundee.	C. Horrex, M.Sc., Ph.D., Chemistry Department, The University, St. Andrews.
Sheffield.	H. J. V. Tyrrell, M.A., B.Sc., Chemistry Department, The University, Sheffield, 10.
South Africa.	Professor F. L. Warren, Ph.D., F.R.I.C., Department of Chemistry, University of Natal, P.O. Box 375, Pietermaritzburg, South Africa.
Southampton.	N. B. Chapman, M.A., Ph.D., Department of Chemistry, The University, Southampton.
South Wales.	K. W. Sykes, M.A., B.Sc., D.Phil., Department of Chemistry, University College, Singleton Park, Swansea.

PROCEEDINGS
OF THE
CHEMICAL SOCIETY

OFFICIAL ANNOUNCEMENTS

DEATHS

The Council regrets to announce the deaths of the following Fellows:

	Elected.	Died.
Cyril Barnett (Stanmore)	Nov. 11th, 1948.	Oct. 1954.
Derek Arthur Higgins (Wolverhampton)	Nov. 11th, 1948.	April 23rd, 1955.
Harry Selikman (Transvaal)	June 12th, 1928.	April 10th, 1944.
George Spall (London, S.E.1)	June 16th, 1921.	April 28th, 1955.
Ernest Walter Taplin (Gt. Yarmouth)	Dec. 2nd, 1909.	Feb. 10th, 1955.

CONGRATULATIONS.

The President has conveyed the congratulations of the Society to the following Fellows who completed 50 years of Fellowship on June 14th, 1955:

Ralph Emerson de Lury (Ottawa).
Herbert Henstock (Mold).
William Bradshaw Tuck (Epsom).

ELECTION OF NEW FELLOWS.

The following 33 candidates were elected Fellows of the Society on June 2nd, 1955:

Joanne Arnheim.
Beldon Bensley.
Percival Alfred Bosanquet.
Robert James Crawford.
Ugo Croatto.
Walter Davis.
Paulus De Bruyn.
Anthony John Edwards.
Michael John Egerton.
Paul Emmott.
Gordon James Falconer.
Bernard Goldstein.
Alan James Grimes.
Betty Eunice Hill.
Timothy George Hoult.
Ronald Mark Johnson.
Norman Charles Knight.
Brian Arthur Knights.
John Douglas Mackenzie.
Joseph Matt.
Paul Müller.
William Lewis Nobles.
Octavius Santos Pascual.
Sahdeo Prasad Pathak.
John James Roberts.
Mitchell Nicolson Rodger.
Brian Discombe Shepherd.
Barry Owen Shorthouse.
Alberto Spada.
John Frederick Warder.
Arthur Alan Williams.
Alan David Winser.
Raymond Richard Wittekind.

ACKNOWLEDGMENT.

The Council wishes to acknowledge the receipt of an anonymous donation from a Fellow of the Society of £10 to the Research Fund.

SCIENTIFIC MEETINGS.

The following dates of Scientific Meetings during the Session 1955—1956 have been approved by Council :

1955.	1956.
Thursday, October 20th.	Thursday, January 19th.
Thursday, November 3rd.	Thursday, February 2nd.
Thursday, November 17th.	Thursday, February 16th.
Thursday, December 1st.	Thursday, March 15th.
Thursday, December 15th.	Thursday, May 3rd.
	Thursday, June 7th.

The Anniversary Meetings will be held in Nottingham from March 26th to 28th, 1956.

LIBRARY.

To permit extensive refurnishing and reorganisation, the Library will be closed from July 4th to August 15th, inclusive.

QUARTERLY REVIEWS.

The following have agreed to serve on Panels for *Quarterly Reviews* during 1955—1956 :

Organic Chemistry Panel.

Dr. W. A. Waters (Convener).
Professor M. Stacey.
Professor E. R. H. Jones.

Physical Chemistry Panel.

Dr. N. Sheppard (Convener).
Professor C. E. H. Bawn.
Professor A. R. Ubbelohde.

Inorganic Chemistry Panel.

Dr. H. Irving (Convener).
Dr. F. Fairbrother.
Professor H. J. Emeléus.

Quarterly Reviews, Vol. IX, No. 2, will contain the following articles :

" A study of the porous structure of active carbons using a variety of methods," by Academician M. M. Dubinin.

" Chemistry of the boron hydrides," by F. G. A. Stone.

" The chemistry of 5-oxazolones," by E. Baltazzi.

" The chemistry of the nitrosyl group (NO)," by C. C. Addison and J. Lewis.

It is expected that forthcoming issues will contain the following articles :

" Alkyl–oxygen heterolysis in carboxylic esters and related compounds," by A. G. Davies and J. Kenyon.

" The estimation of thermodynamic properties for organic compounds and chemical reactions," by G. J. Janz.

" Biological methylation," by F. Challenger.

CORDAY-MORGAN MEDAL AND PRIZE.

The Corday–Morgan Medal and Prize, consisting of a Silver Medal and a monetary Prize of 150 Guineas, is awarded annually to the chemist of either sex and of British Nationality, who, in the judgment of the Council of the Chemical Society, shall have published during the year in question the most meritorious contribution to experimental chemistry, and who shall not, at the date of publication, have attained the age of thirty-six years. The Council has power to suspend the award in any year in which no suitable candidate presents himself or is brought to the notice of the Council.

Copies of the rules governing the award may be obtained from the General Secretary.

Applications or recommendations in respect of the award for the year **1954** must be received not later than December **31st, 1955**, and applications for the award for **1955** are due before the end of **1956**.

RESEARCH FUND.

A meeting of the Research Fund Committee will be held in November next. All persons who have received grants, and whose accounts have not been declared closed by the Council, are informed that reports must be received by the Society not later than November **1st, 1955**.

Applications for grants, to be made on forms available from the General Secretary, must be received on or before November 15th, 1955. Applications from Fellows will receive prior consideration.

Attention is drawn to the fact that the income arising from the donation of the Worshipful Company of Goldsmiths is principally devoted to the encouragement of research in inorganic and metallurgical chemistry and that the income from the Perkin Memorial Fund is to be applied to investigations relating to problems connected with the coal-tar and allied industries.

MINUTES OF SCIENTIFIC MEETINGS

Minutes of a

SCIENTIFIC MEETING

held at Burlington House, on Thursday, May 5th, 1955, at 7.30 p.m.

The President, PROFESSOR W. WARDLAW, C.B.E., D.Sc., F.R.I.C., was in the Chair.

MINUTES.

The Minutes of the Scientific Meeting held at the Royal Institution on March **31st, 1955**, were read, and were confirmed and signed.

FORMAL ADMISSION OF FELLOWS.

The following were admitted Fellows of the Society : D. J. Cram, G. T. Young.

SCIENTIFIC COMMUNICATIONS.

The following papers were read and discussed :

"Polynucleotide Synthesis. Thymidine 3′ : 5′-Dinucleotide." By A. M. Michelson and Sir Alexander R. Todd.

"The Chemistry of Fungi. Part XXVI. Rosonolactone." By A. Harris, A. Robertson, and W. B. Whalley.

"The Red Colour given by Coal-tar Phenols and Aqueous Alkalis. Isolation of a Quinone derived from a Tetrahydroxytetramethyldiphenyl." By W. Baker and D. Miles.

Minutes of a

SCIENTIFIC MEETING

held in the Department of Chemistry, The University, Leeds, on Wednesday, May 18th, 1955, at 10 a.m.

The President, PROFESSOR W. WARDLAW, C.B.E., D.Sc., F.R.I.C., was in the Chair and replied to Sir Charles Morris, M.A., LL.D., D.Litt., Vice-Chancellor of the University of Leeds, who welcomed the Society.

FORMAL ADMISSION OF FELLOWS.

The following were admitted Fellows of the Society: Herbert C. Brown, P. Waterhouse, J. N. Baxter, W. A. Lomax, J. Malcolm Bruce, J. Addy, D. Booth, J. S. Whittaker, S. Varma, D. B. Wootton, Patrick Nield, C. A. Bartram, A. K. Barbour, E. T. Crisp, N. H. Keir, Peter Smith.

SYMPOSIUM.

The President called upon Professor B. Lythgoe to take the Chair for the morning session of the Symposium entitled "The Friedel–Crafts Reaction." The following contributions were made and discussed:

"Self-union of Aromatic Ketones brought about by Aluminium Chloride and Other Reagents," by Professor W. Bradley (Leeds).

"Evidence for a Displacement Mechanism in the Friedel–Crafts Reaction," by Professor H. C. Brown (Purdue University).

"The Production of Carbonium Ions from Tertiary Acid Chlorides," by Dr. E. Rothstein (Leeds).

"The Formation of Carbonium Ions by the Action of Metallic Salts," by Professor A. G. Evans (Cardiff).

The meeting adjourned for lunch, and in the afternoon the Chair was taken by Professor F. S. Dainton. The following papers were read and discussed:

"A Comparison of Inter- and Intra-molecular Friedel–Crafts Processes," by Dr. G. Baddeley (Manchester).

"Aluminium Halide Complexes with Nitrogen Bases," by Professor D. D. Eley (Nottingham).

"Complex Formation in some Polyvalent Metal Halide Systems," by Dr. F. Fairbrother (Manchester).

"The Rôle of Water in Reactions of Stannic Chloride in Organic Media," by Dr. R. O. Colclough (Leeds).

"Chain-stopping Processes in the Friedel–Crafts Polymerisations," by Dr. D. C. Pepper (Dublin).

"Some Theoretical Considerations concerning the Relative Efficiency of Different Types of Cationic Catalysts," by Dr. P. H. Plesch (Keele).

In closing the meeting, the Chairman expressed the thanks of the Society to the contributors to the Symposium.

LIST OF APPLICATIONS FOR FELLOWSHIP

(Fellows wishing to lodge objections to the election of these candidates should communicate with the Honorary Secretaries within ten days of the date of publication of the Journal *for June, 1955. Such objections will be treated as confidential. The forms of application are available in the Library.)*

Ali, Md. Erfan, M.Sc. (Dacca). Pakastani. Department of Organic Chemistry, Royal College of Science, London, S.W.7. Post-graduate Student. *Signed by:* L. N. Owen, E. A. Braude.

Archer, Derek Paul, B.Sc. and Ph.D. (Lond.). British. R.O.F. Guest House, Factory Road, Burry Port, Carms. Industrial Chemist. *Signed by:* M. F. Ansell, W. J. Hickinbottom.

Arnowich, Beatrice, A.B. (Vassar Coll.), M.S. (Michigan). American. 845, West End Avenue, New York 25, New York, U.S.A. Teaching Fellow at New York University. *Signed by:* T. S. Ma, R. T. Morrison.

Bache, Bryon William, B.A. (Oxon.). British. Keble College, Oxford. Research Student. *Signed by:* L. A. K. Staveley, P. H. T. Beckett.

Baddiel, Colin Brian. British. 14, Glanbrydan Avenue, Uplands, Swansea. Student at University College, Swansea. *Signed by:* K. W. Sykes, G. H. R. Summers.

Barrett, Keith Edwin James, B.A. (Oxon.). British. 3, Egerton Road, Chorlton-cum-Hardy, Manchester, 21. Research Chemist. *Signed by:* A. C. Farthing, D. S. Davies.

Baxendale, John Hodson, D.Sc. (Manc.). British. 43, Clothorn Road, Didsbury, Manchester, 20. Senior Lecturer at The University, Manchester. *Signed by:* G. R. Barker, G. D. Meakins.

Bickel, Albert Frederik, Ph.D. (Amsterdam), D.Phil. (Oxon.). Dutch. Sloestraat 10III, Amsterdam, Netherlands. Research Chemist at Koninklijke Shell-Laboratorium, Amsterdam. *Signed by:* E. C. Kooyman, W. A. Waters.

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6210. "Mechanism of substitution at a saturated carbon atom. Part XLVI. Kinetics of the interaction of iodide ions with simple alkyl bromides in acetone." By L. FOWDEN, E. D. HUGHES, and C. K. INGOLD.

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6312. "Studies in mycological chemistry. Part II. Proof of the constitution of flaviolin (2 : 5 : 7-trihydroxy-1 : 4-naphthaquinone) by a synthesis of tri-*O*-methylflaviolin." By J. E. DAVIES, F. E. KING, and JOHN C. ROBERTS.

6313. "Studies in mycological chemistry. Part III. Some hydroxy- and methoxybenzenepolycarboxylic acids." By JOHN C. ROBERTS.

6315. "The chemistry of extractives from hardwoods. Part XXV. (−)-*epi*Afzelechin, a new member of the catechin series." By F. E. KING, J. W. CLARK-LEWIS, and (in part) W. F. FORBES.

6322. "Studies in the polyene series. Part L. 'Anhydrovitamin A_2'." By H. B. HENBEST, E. R. H. JONES, T. C. OWEN, and V. THALLER.

6323. "Studies in the polyene series. Part LI. Conversion of vitamin A_1 into vitamin A_2." By H. B. HENBEST, E. R. H. JONES, and T. C. OWEN.

6324. "3-Methyl(and 3-ethyl)-2-2'-pyridylindole." By YEE-SHENG KAO and SIR ROBERT ROBINSON.

6328. "The preparation of halogen bridged complexes of platinum(II)." By J. CHATT and L. M. VENANZI.

6332. "4 : 4-Dimethyl-steroids. Part I. 4 : 4-Dimethylcalciferol." By G. COOLEY, B. ELLIS, and V. PETROW.

6334. "A synthesis of methyl homologues of naphthols and dihydroxynaphthalenes." By NG. PH. BUU-HOÏ and DENISE LAVIT.

ADDITIONS TO THE LIBRARY

I. *Donations*

A. *Books.*

BROGLIE, LOUIS DE. Mécanique ondulatoire et cinétique chimique. Réunions d'études et de mises au point, tenues sous la présidence de Louis de Broglie. Paris, 1955. (*Recd.* 28/4/55.)

From the Publishers: Editions de la *Revue d'Optique Théorique et Instrumentale.*

HOPKIN & WILLIAMS LTD. Organic reagents for metals, and other reagent monographs, 5th ed. Vol. 1. Edited by W. C. JOHNSON. Chadwell Heath, 1955. 15*s.* (*Recd.* 2/5/55.) From the Publishers: Messrs. Hopkin & Williams Ltd.

MILES, FRANK DOUGLAS. Cellulose nitrate; the physical chemistry of nitrocellulose, its formation and use. London, Oliver & Boyd, 1955. 45*s.* (*Recd.* 18/5/55.)

From I.C.I., Ltd., Nobel Division.

MULLINS, B. P. Spontaneous ignition of liquid fuels. London, Butterworths Scientific Publications, 1955. 20*s.* (*Recd.* 18/5/55.)

From the Ministry of Supply.

OPENSHAW, H. T. A laboratory manual of qualitative organic analysis, 3rd ed. Cambridge Univ. Pr., 1955. 10*s.* 6*d.* (*Recd.* 27/4/55.)

From the Author: Dr. H. T. Openshaw.

ROBINSON, SIR ROBERT. The structural relations of natural products. Being the first Weizmann memorial lecture. December, 1953. Oxford, Oxford Univ. Pr., 1955. 25*s.* (*Recd.* 10/5/55.)

From the Author: Sir Robert Robinson.

SUTTON, F. A systematic handbook of volumetric analysis, 13th ed. Revised . . . by J. Grant. London, Butterworths Scientific Publications, 1955. 63*s.* (*Recd.* 20/4/55.)

From C. Sutton, Esq.

B. *Pamphlets.*

SMITH, G. FREDERICK. The determination of butterfat in ice cream and ice cream mix. Columbus, Ohio, 1954.

SMITH, G. FREDERICK. The trace element determination of copper and mercury in pulp and paper. Columbus, Ohio, 1954.

SMITH, G. FREDERICK. The wet ashing of organic matter employing hot concentrated perchloric acid. Columbus, Ohio, 1954.

MADDISON, R. E. W. Studies in the life of Robert Boyle, F.R.S. Part V. Boyle's operator: Ambrose Godfrey Hanckwitz, F.R.S. London, 1955.

II. *By purchase*

AMERICAN CHEMICAL SOCIETY. Use of sugars and other carbohydrates in the food industry. Washington, D.C., The Society, 1955. (Advances in Chemistry Series, No. 12.) 27*s.* (*Recd.* 17/5/55.)

ASAMI, Y., and HIGASI, K., *Editors.* Molecular structure and related problems. Sapporo, The Research Institute of Applied Electricity, Hokkaido University, 1954. 25*s.* (*Recd.* 2/5/55.)

HARRIS, LESLIE J. Vitamins in theory and practice, 4th ed. Cambridge, Cambridge Univ. Pr., 1955. 35*s.* (*Recd.* 23/5/55.)

HILL, R., and WHITTINGHAM, C. P. Photosynthesis. London, Methuen & Co., Ltd., 1955. (Methuen's Monograph on Biochemical Subjects.) 8*s.* 6*d.* (*Recd.* 26/4/55.)

MÖLLERING, I., and MÖLLERING, H. Verfahren der Gerbereichemie. Stuttgart, Wissenschaftliche Verlagsgesellschaft M.B.H., 1954. £6. (*Recd.* 26/4/55.)

PROCEEDINGS
OF THE
CHEMICAL SOCIETY

OFFICIAL ANNOUNCEMENTS

BIRTHDAY HONOURS LIST.

The President has conveyed the congratulations of the Society to the following Fellows whose names appear in the Birthday Honours List:

K.B.E.
Alexander Fleck.

C.B.
Norman Charles Wright.

CITATION OF REFERENCES IN THE JOURNAL

Notices to Authors. On the recommendation of the Publication Committee it has been decided by the Council that, starting in January 1956, references cited in the *Journal* shall be as numbered footnotes.

All manuscripts submitted henceforth should have the references in the new style.

Authors are requested to note the following details. The only changes from existing practice are the use of footnotes and simplifications resulting therefrom.

Numerals.

1. References will be given numbers consecutive throughout the paper. These will be written as superior arabic numerals, without parentheses, after the appropriate name or word.

2. When citation of a paper is repeated, the numeral previously given to that reference will be used also at the second citation, and the footnote will not be repeated. With this exception, numerals must be consecutive (*i.e.*, the footnote may not be deferred).

3. The position of the numeral should be carefully chosen, particularly when it does not follow a name. If placed adjacent to punctuation, the numeral should normally be placed after the punctuation mark, *e.g.*, " This is probably the *cis*-form,[3] but . . ." However, if essential to avoid confusion, the numeral may precede the punctuation mark, as in *e.g.*, " The method is suitable for lead [4], tin [5], bismuth [6], and mercury.[7] "

4. The reference numeral should not follow a number or a physical unit, *e.g.*, " Smith's value [6] was 2·7 " and " Smith [2] found 26·2 cm." should be used in place of a version ending 2·7 [6] cm.[2]

Names.

5. The names of authors will always be given in the footnotes, but this will not prevent some or all of the names (and dates) being mentioned also in the cursive text, if desired.

6. Normally, all the authors' names must be cited at first mention, but see p. 80 for composite references.

7. Initials of authors will not be given unless this is necessary to avoid confusion.

Composite References.

8. The style for composite references customary hitherto in the *Journal* will be followed, *e.g.*:

[6] Smith, *J.*, **1954**, **167**, 742.
[7] Jones, *J.*, **1953**, **267**; **1954**, 1742.
[8] Black, *J.*, **1954**, **367**; *J. Amer. Chem. Soc.*, **1954**, **76**, 2742.
[9] White, *J.*, **1954**, **467**; Jones and Smith, *J. Amer. Chem. Soc.*, **1954**, **76**, 3742.

9. If only one paper from a composite reference is required for citation later, then two numbers may be assigned to the first citation (*e.g.*, Smith [6,7]) with two footnotes; alternatively, long composite references may be divided by letters, *e.g.*,

[7] Smith, *J.*, (*a*) **1953**, **267**; (*b*) **1954**, **1742**; (*c*) etc.
[9] (*a*) Smith, *J.*, **1954**, **467**; (*b*) Jones and Smith, *J. Amer. Chem. Soc.*, **1954**, **76**, 3742; (*c*) etc.

10. A composite reference may cite a previous reference in the form:

[10] Smith, *J.*, **1954**, **567**; Jones, ref. 6.

11. If co-authors are to be collectively cited, as in " Smith and co-workers " or " Smith *et al.*," the latter of these forms is inappropriate unless the individual name " Smith " appears first among the authors' names in the original paper. (For cursive text, a fuller form such as " Smith and his co-workers " is preferable to " Smith and co-workers.")

Journals.

12. References must be abbreviated to the form customary in the *Journal* (see examples above). A list of titles and the abbreviations now in use is given at the end of *Annual Reports* for **1954**, vol. **51** (published **1955**). The abbreviations in *Current Chemical Papers*, 1955, No. 1, are confined to current journals. These lists supersede, and differ in a few places from, the list at the end of the brochure " Presentation of Papers."

13. When a footnote reference refers to the journal or author(s) cited in the immediately preceding footnote, the following abbreviations are used:

Authors.	Journal.	Year.	Page.	Example.
Same	Same	Same	Different	[6] *Idem*, *ibid.*, p. 4742.
Same	Same	Different		[6] *Idem*, *ibid.*, 1954, **76**, 4742.
Same	Different			[6] *Idem*, *J. Amer. Chem. Soc.*, 1954, **76**, 4742.
Different	Same	Same	Different	[6] Jones, *ibid.*, p. 4742.
Different	Same	Different		[6] Jones, *ibid.*, 1954, **76**, 4724

The abbreviated title is repeated when shorter than *ibid.*, for example, *J.*, *Ber.*

The same forms are used when there is a change of authors in one composite reference, *e.g.*:

[6] Smith, *J. Amer. Chem. Soc.*, **1954**, **76**, 474; Jones, *ibid.*, p. 747.

However, the journal does not need to be repeated if there is no change of author within a composite reference, *e.g.*:

[6] Smith, *J. Amer. Chem. Soc.*, **1954**, **76**, 474, 747; **1955**, **77**, 23.

(For the first footnote on a printed page, the printers will replace *idem* or *ibid.* by the previous entry.)

14. Patents are given in the form: B.P. **567,450**, **567,455**. U.S.P. **2,171,230**. G.P. **436,112—4**. Dates may be indicated thus: B.P. Appln. **1473/1950**. B.P. **666,876/1948**.

15. Titles of books are cited in quotation marks, in roman letters; the author, title, publisher, town, date (or edition if more than one has been published), and (if required) page number are given in that order, *e.g.*, Peters and Van Slyke, " Quantitative Clinical Chemistry," Williams and Wilkins Co., Baltimore, **1946**, Vol. I, p. **221**.

16. Reference to a different page of a book previously cited should be in the form: ref. **6**, p. **176**.

Other Footnotes.

17. Sparing use may be made of footnotes for textual comment or "asides," as at present, and such footnotes should be indicated by asterisks (*), daggers (†), double daggers (‡), etc.

18. Reference footnotes must contain only the actual references; any comment thereon should be in the cursive text, or, in exceptional cases, in asterisk footnotes.

19. In Series of papers, the Part number in the title is to be marked with an asterisk (as at present), the reference to the previous Part being given as a footnote marked with an asterisk. If later reference to this Part is made, the full reference will be repeated, this time with its appropriate numeral.

Manuscript.

20. In manuscript, reference footnotes may be typed at the foot of the appropriate page or as a list at the end of the manuscript. They should be in double-line spacing. The reference numerals should be superscripts (without parentheses or full stops). Journal titles, *idem*, *ibid.*, and volume numbers should be underlined.

21. Authors submitting manuscripts previously prepared in the old form are requested to convert them into the new form: all that this entails is a typed list of the references in the order in which they were cited, with numerals replacing the references previously given in the text.

Minutes of a

SCIENTIFIC MEETING

held at Burlington House, on Thursday, 2nd June, 1955, at 7.30 p.m.

The President, PROFESSOR W. WARDLAW, C.B.E., D.Sc., F.R.I.C., was in the Chair.

MINUTES.

The Minutes of the Scientific Meetings held at Burlington House on May 5th and at the University of Leeds on May 18th, 1955, were read, and were confirmed and signed.

FORMAL ADMISSION OF FELLOWS.

The following were admitted Fellows of the Society: M. M. Coombs, Roy Foster, J. P. de Villiers, M. A. Wheelans, T. Colclough, M. A. Place, P. B. Brindley, M. Davies.

CENTENARY LECTURE.

The President introduced Professor H. C. Brown, Ph.D., of Purdue University, and called upon him to deliver the Centenary Lecture entitled "Chemical Effects of Steric Strains." At the conclusion of the Lecture, a vote of thanks to Professor Brown, proposed by the President, was carried with acclamation.

Minutes of a

SCIENTIFIC MEETING

held jointly with the Alembic Club in the Physical Chemistry Laboratory, South Parks Road, Oxford, on Monday, June 6th, 1955, at 8.15 p.m.

The President, PROFESSOR W. WARDLAW, C.B.E., D.Sc., F.R.I.C., was in the Chair, and replied to Dr. C. J. Danby, who, on behalf of the Alembic Club, welcomed the Society to Oxford.

FORMAL ADMISSION OF FELLOWS.

The following were admitted Fellows of the Society: D. Ll. Hammick, R. H. Ramsden, A. C. Day, Michael W. Perrin, D. L. Swallow, M. L. Tomlinson, B. Brocklehurst, R. E. Thornton, D. G. Brooke, L. E. Anderson, G. H. Singer, D. A. Long, D. A. Bekoe, Robert

M. Haines, B. A. Green, David G. Jenkin, G. I. Fray, M. V. Cooksley, C. M. Staveley, M. Avery, G. Saville, L. A. Wiles, J. R. H. Whiston, Anthony White, J. A. G. Collier, J. S. A. Brunskill, Timothy F. Wheatley, David H. Watson, G. Ryback, D. A. Dominey, K. Borer, H. J. De Nordwall, R. K. Webster, R. A. Gregory, A. Marchant, D. W. Davies, N. F. Taylor, R. W. Yorke, J. J. Cox, T. J. Harper, N. A. Smart, J. W. Powell, Colin Topliss, D. C. Nonhebel, M. S. Gibson, Geoffrey G. Coker, Harold J. Stern, M. Hely Hutchison, A. L. J. Beckwith, Donald K. Dougall, J. K. Heyes, D. M. Russell, J. Spreadborough, T. G. Corbin, A. E. J. Herbert, J. S. Littler, C. W. Jefford, J. Humphreys, M. Redstone, David B. Wootton, D. F. Evans, F. J. Stubbs.

LECTURE.

The Chairman called upon Sir Robert Robinson, O.M., F.R.S., to deliver the lecture entitled " Some Analytic and Synthetic Studies of Natural Products." A vote of thanks to Sir Robert Robinson, proposed by Professor E. D. Hughes, was carried with acclamation.

LIST OF APPLICATIONS FOR FELLOWSHIP

(*Fellows wishing to lodge objection to the election of these candidates should communicate with the Honorary Secretaries within ten days of the date of publication of the* Journal *for July, 1955. Such objections will be treated as confidential. The forms of application are available in the Library.*)

Berkowitz, Lewis Maurice, A.M. (Columbia), B.S. (City Coll., N.Y.). American. 1234, Stratford Avenue, Bronx 72, New York, U.S.A. Student. *Signed by:* G. Stork, E. Trachtenberg.

Clark, Keith Jasper, M.A. (Oxon.). British. 74, Lonsdale Road, Oxford. Research. *Signed by:* L. A. K. Staveley, R. Brettle.

Davies, Noel Hugh, B.Sc. (Wales). British. 57, Glanbrydan Avenue, Uplands, Swansea. Student at University College, Swansea. *Signed by:* K. W. Sykes, G. J. James.

Downes, John Barker. British. 61, Ramsey Road, Dovercourt, Essex. Student. *Signed by:* R. A. Tingey, R. D. Langstaff.

Edge, Robert Arthur, M.Sc. (Cape Town). South African. P.O. Box 1012, Johannesburg, South Africa. Inorganic Chemist with the Anglo-American Corporation of South Africa, Ltd. *Signed by:* F. Sebba, R. Hanley Marks.

Few, John Dennis, B.Sc. (Lond.). British. 44, Dukes Avenue, London, W.4. Technician in the Chemical Pathology Department, Charing Cross Hospital Medical School. *Signed by:* J. Patterson, W. O. Sykes.

Fisher, James Wotherspoon, B.Sc. (Lond.), F.R.I.C. British. 4, Mill Lane, St. Ippolyts, Nr. Hitchin, Herts. Manager, British Celanese, Ltd., Luton. *Signed by:* K. D. Grice, J. R. Young.

Hammond, Eric Walter, B.Sc. (Lond.), A.R.I.C. British. 73, Weigall Road, Lee, London, S.E.12. Experimental Officer at the Government Laboratory, W.C.2. *Signed by:* W. T. Cresswell, J. Leicester.

Haworth, Norman David, B.A. (Oxon.). British. 14, St. Georges Court, Gloucester Road, London, S.W.7. Student. *Signed by:* L. A. K. Staveley, L. E. Sutton.

Holmes, Enid Gillian. British. 85, London Road, Wembley, Middlesex. Student at King's College, London. *Signed by:* S. H. Harper, D. H. Hey.

Hsu, Wei-Hwa, B.Sc. (Shanghai), Ph.D. (Leeds). Chinese. 76, West Cromwell Road, London, S.W.5. Research Chemist. *Signed by:* E. Rothstein, P. A. Briscoe.

Laundy, Brian John Russell, B.Sc. (Lond.). British. 9, Rothbury Road, Hove 3, Sussex. Assistant Experimental Officer at Atomic Energy Research Establishment, Harwell. *Signed by:* D. F. C. Morris, E. N. Jenkins.

Palmer, Malcolm George. British. 32, High Street, Manningtree, Essex. Student. *Signed by:* R. A. Tingey, S. Lewin.

Pandit, Prem Nath, B.Sc. (Panjab), Ph.D. (Bombay). Indian. Colour Chemistry Department, The University, Leeds, 2, Yorks. Research Fellow. *Signed by:* W. Bradley, R. B. Cundall.

Poulson, Arthur Hamilton. British. Glenrobin, 169, Hamilton Road, South Mount Vernon, Glasgow, E.2. Technical Assistant with the Scottish Gas Board. *Signed by:* C. A. Poulson, M. S. Gaskill.

Ratcliffe, David Bernard. British. 51, London Road, Lexden, Colchester, Essex. Student. *Signed by:* R. D. Langstaff, R. A. Tingey.

Riley, Frank Lewis. British. 17 Victoria Park Road, Tunstall, Stoke-on-Trent, Staffs. Student at the University of Leeds. *Signed by:* M. R. Truter, E. Rothstein.

Shavel, John, jun., M.S. (Polytech. Inst. of Brooklyn), Ph.D. (Notre Dame). American. 673, Palmer Avenue, Maywood, New Jersey, U.S.A. Research Chemist. *Signed by:* J. A. King, E. H. Sakal.

Sherwin, Ernest, B.Sc. (Lond.). British. 34, West Street, Drighlington, Bradford, Yorks. Assistant Lecturer at the Technical College, Bradford. *Signed by:* R. Hemming, R. L. Edwards.

Stanfield, James Edward. British. Christchurch, Oxford. Student. *Signed by:* L. A. K. Staveley D. A. Long.

Turner, Jessie Irene, B.Sc. (Lond.). **British.** c/o Mrs. James, The Bungalow, Berry Hill, Nr. Coleford, Glos. Chemistry Mistress at Bell's Grammar School, Coleford. *Signed by:* M. Stacey, S. J. Featherston.

Turner, Kenneth, B.Sc. (Liv.). British. 21, Gayhurst Crescent, West Derby, Liverpool, 11. Research Student. *Signed by:* W. B. Whalley, R. J. S. Beer.

Williams, Neil Russell, B.A. (Cantab.). British. King's College, Cambridge. Research Student. *Signed by:* G. W. Kenner, C. Djerassi.

Witherington, Paul, B.Sc. and M.A. (Oxon.). British. Monkton Combe School, Nr. Bath, Somerset. Chemistry Master. *Signed by:* F. M. Brewer, G. D. Parkes.

UNDER SPECIAL PROVISION APPERTAINING TO CANDIDATES RESIDENT ABROAD.

Andrews, Arthur Clinton, M.S. (Kansas State Coll.), Ph.D. (Wisconsin). American. Chemistry Department, Kansas State College, Manhattan, Kansas, U.S.A. Professor. *Signed by:* S. Searles, jun.

Anyanwu, Nwaese, B.A. (San Francisco.) 2436, Clay Street, San Francisco, California, U.S.A. Chemist at the Mount Zion Hospital, San Francisco. *Signed by:* H. C. Prosser.

De, Rajendra Lal, M.B. (Calcutta). Hindu. 4, Beadon Street, Calcutta, 6, India. Physician and Research worker. *Signed by:* J. C. Bardhan.

Holloway, Frank Leroy, B.Ed. (Southern Ill.), M.S. and Ph.D. (Chicago). American. 3346, Lincoln Circle S., Allentown, Pa., U.S.A. Chief Chemist with Air Products, Inc., Pennsylvania. *Signed by:* A. Maggiolo.

Ludwig, Bernard J., M.S. (Vermont), Ph.D. (Columbia). American. Stockton Place, Colonial Gardens, New Brunswick, New Jersey, U.S.A. Chief Chemist with Carter Products, Inc., New Brunswick. *Signed by:* W. T. Holfeld.

Masuelli, Frank John, Ph.D. (Virginia Polytech. Inst.). American. P.O. Box 2, Rockaway, New Jersey, U.S.A. Research Chemist at Picatinny Arsenal, New Jersey. *Signed by:* C. Schuerch.

PAPERS ACCEPTED

(List of Papers accepted between May 25th and June 27th, 1955, for publication in the *Journal.*)

Numbers quoted are "Reprint Order Numbers." Reprints may be ordered from the list below, or from the published *Journal* (January 1954 onwards). Orders must be sent to the General Secretary accompanied by a remittance for 5*s.* for each reprint, or by the appropriate number of reprint vouchers.

5906. "*cyclo*Hexane derivatives. Part I. Preparation of *cis*- and *trans*-3 : 3 : 5-trimethyl*cyclo*hexanol and proof of configuration." By E. G. Peppiatt and R. J. Wicker.

5968. "2 : 4 : 6-Tri-iodophenyl *iso*cyanate as a reagent for hydroxy- and amino-groups." By J. D. A. Johnson.

51014. "Exchange reactions and magnetic susceptibilities of complex salts. Part II. Magnetic susceptibilities of some complex nickel salts." By H. C. Clark and A. L. Odell.

51015. "Exchange reactions and magnetic susceptibilities of complex salts. Part III. Exchange reactions of some nickel complexes." By H. C. Clark and A. L. Odell.

6003. "The stereochemistry of the tropane alkaloids. Part VI. The configuration of the nitrogen atom in tropane-3α : 6β-diol, oscine, and of the derived quaternary salts." By Gabor Fodor, Jozsef Toth, and Iren Vincze.

6009. "Pyrone series. Part II. 4 : 5 : 6-Triaryl-2-pyrones." By Gabra Soliman and Ibrahim El-Sayed El-Kholy.

6025. "The kinetics and mechanism of the reactions of the trimethylhalogenosilanes with methylmagnesium halides." By A. F. Reid and C. J. Wilkins.

6157. "The synthesis and cleavage of 9-phenanthryl phenyl ether." By R. L. Huang.

6159. "Kinetics and mechanism of aromatic halogenation by hypohalous acids. Part II. Directive effects of substituents in the bromination of aromatic ethers by hypobromous acid." By S. J. Branch and Brynmor Jones.

6191. "Observations on the ozonolysis of allylic compounds. The structure of geraniol." By J. Knights and E. S. Waight.

6267. "The chemistry of dammar resin." By J. S. Mills and A. E. A. Werner.

6269. "Experiments on the synthesis of substances related to the sterols. Part LII. Some condensations of substituted β-diketones, including an account of a new molecular rearrangement." By A. R. Pinder and Sir Robert Robinson.

6270. "Experiments on the synthesis of substances related to the sterols. Part LIII. Stereospecific synthesis of a tricyclic ketone." By J. W. CORNFORTH, O. KAUDER, J. E. PIKE, and SIR ROBERT ROBINSON.

6274. "An ion-exchange method for the separation of partially methylated sugars, and its application in an improved preparation of 2-*O*-methyl-D-glucose." By M. V. LOCK and G. N. RICHARDS.

6275. "The mechanism of the Ullmann diaryl synthesis." By HARRY E. NURSTEN.

6280. "Structural aspects of the hydrolysis of titanium tetraethoxide." By D. C. BRADLEY, R. GAZE, and W. WARDLAW.

6286. "The electrical conductivity of dinitrogen tetroxide solutions in sulphuric, selenic, and phosphoric acid." By G. HETHERINGTON, M. J. NICHOLS, and P. L. ROBINSON.

6289. "Researches on acetylenic compounds. Part LI. The synthesis of γ-methyleneglutamic acid and γ-methyleneglutamine." By P. C. WAILES and M. C. WHITING.

6290. "4′ : 5′-Dihydroglyoxalino(2′ : 1′-2 : 3)thiazolium salts, and the ultraviolet light absorption of thiazole derivatives." By WALTER WILSON and R. WOODGER.

6294. "Alkenylation employing lithium alkenyls. Part IX. Synthesis of dimethylbutadienecarboxylic acids." By E. A. BRAUDE and E. A. EVANS.

6295. "Alkenylation with lithium alkenyls. Part X. Some reactions of trimethylvinyl-lithium (1 : 2-dimethylpropenyl-lithium)." By E. A. BRAUDE and E. A. EVANS.

6296. "Alkenylation employing lithium alkenyls. Part XI. A new synthesis of ethylenic aldehydes." By E. A. BRAUDE and E. A. EVANS.

6297. "Alkenylation with lithium alkenyls. Part XII. The carboxylation of 1- and 2-(3 : 4-dihydronaphthyl)-lithium." By E. A. BRAUDE and E. A. EVANS.

6311. "Triterpenoids. Part XLII. The configuration of the carboxyl group in glycyrrhetic acid." By J. M. BEATON and F. S. SPRING.

6314. "Studies in mycological chemistry. Part IV. Purpurogenone, a metabolic product of *Penicillium purpurogenum* Stoll." By JOHN C. ROBERTS and C. W. H. WARREN.

6318. "Some physical properties of aliphatic diphosphonates. Part I. Ethyl esters." By GENNADY M. KOSOLAPOFF.

6319. "Infrared spectra and crystallinity. Part III. Poly(ethylene glycol)." By W. H. T. DAVISON.

6320. "2-Acyl derivatives of cyclic 1 : 3-diones. Part II. The structures of angustione and dehydroangustione." By W. R. CHAN and C. H. HASSALL.

6321. "Geometrical isomerism of the azonaphthalenes." By MAX FRANKEL, REUVEN WOLOVSKY, and ERNST FISCHER.

6325. "The preparation and hydrolysis of some esters of 2 : 4 : 6-triphenylbenzoic acid. Part I. Preparation of the esters." By J. GRAHAM and J. R. QUAYLE.

6326. "The preparation and hydrolysis of some esters of 2 : 4 : 6-triphenylbenzoic acid. Part II. The mechanisms of hydrolysis." By C. A. BUNTON, A. E. COMYNS, J. GRAHAM, and J. R. QUAYLE.

6331. "The kinetics of ester hydrolysis in concentrated aqueous acids." By R. P. BELL, A. L. DOWDING, and J. A. NOBLE.

6333. "Evidence for formation of free-radical intermediates in some reactions involving periodate." By M. C. R. SYMONS.

6335. "Triterpenoids. Part XLIII. The constitution of some compounds obtained by the dehydration of α-amyrin and related alcohols." By C. C. ALLAN, F. S. SPRING, ROBERT STEVENSON, and W. S. STRACHAN.

6336. "Triterpenoids. Part XLIV. The constitution of '*l*-α-amyradiene'." By M. B. E. FAYEZ, JAMES GRIGOR, F. S. SPRING, and ROBERT STEVENSON.

6337. "Lactones. Part II. The structure of mellein." By JOHN BLAIR and G. T. NEWBOLD.

6338. "1-Phenylnaphthalenes." By F. G. BADDAR, H. A. FAHIM, and A. M. FLEIFEL.

6339. "Steroids and Walden inversion. Part XXVI. 4β-Methoxycholest-5-ene, 6β-methoxycholest-4-ene, and related compounds." By D. N. JONES, J. R. LEWIS, C. W. SHOPPEE, and G. H. R. SUMMERS.

6340. "Carissone." By W. A. AYER and W. I. TAYLOR.

6341. "4-Alkyl-3 : 5-dioxo-1 : 2-diphenylpyrazolidine derivatives." By RICHARD BUDZIAREK, D. J. DRAIN, (MISS) F. J. MACRAE, JOHN MCLEAN, G. T. NEWBOLD, D. E. SEYMOUR, F. S. SPRING, and MARTIN STANSFIELD.

6342. "The mechanism of the hydrolysis of acetyl chloride." By V. GOLD and J. HILTON.

6343. "Methoxylated hexahydro-9 : 11-dimethylcarbazole." By M. F. MILLSON and SIR ROBERT ROBINSON.

6344. "Some derivatives of 3 : 6-dimethyl-2 : 5-diphenylpyrazine." By W. F. BEECH.

6346. "4-Bromo- and 4-chloro-cholest-4-en-3-one." By J. I. SHAW and ROBERT STEVENSON.

6348. "Stereospecificity in the Perkin–Oglialoro reaction. The stereochemical configurations of some substituted α-phenylcinnamic acids." By MALCOLM CRAWFORD and C. W. MOORE.

6349. "Liquid metals. Part III. The influence of oxide films on the surface tension of liquid sodium." By C. C. ADDISON, W. E. ADDISON, and D. H. KERRIDGE.

6350. "The constitution and synthesis of leucoanthocyanidins." By F. E. KING and J. W. CLARK-LEWIS.

6351. "Syntheses in the pyridino- and piperidino-(1′ : 2′-*l* : 2)benziminazole series." By K. H. SAUNDERS.

6352. "Infrared spectra of semicarbazones." By W. H. T. DAVISON and (MISS) P. E. CHRISTIE.

6354. "The epimerisation of sugars." By J. K. N. JONES and W. H. NICHOLSON.

6355. "*Lycoris* alkaloids. Part XXXI. A structural interrelation of lycorine and lycorenine." By SHOJIRO UYEO and HARUAKI YAJIMA.

6356. "Absorption spectra and structure of sulphinic acids." By (MISS) S. DETONI and D. HADZI.

6358. "Aryl-2-halogenoalkylamines. Part XIV. Some compounds possessing latent cytotoxic activity." By W. C. J. ROSS, C. P. WARWICK, and, in part, J. J. ROBERTS.

6366. "Lipids. Part III. Determination of hydrogenation selectivity in synthesis of *cis*-fatty acids." By L. CROMBIE.

6367. "The production or carbonium ions by the action of metal salts. Part II. The extinction coefficients of carbonium ions." By J. W. BAYLES, J. L. DOTTER, and ALWYN G. EVANS.

6368. "The effect of solvent on the ionization of organic halides. Part IV. The extinction coefficients of carbonium ions." By ALWYN G. EVANS, I. H. MCEWAN, A. PRICE, and J. H. THOMAS.

6370. "Chemical investigation of Indian lichens. Part XIX. *Lepraria*. Constitution of leprapinic acid." By O. P. MITTAL and T. R. SESHADRI.

6371. "*O*-Alkylation of urea." By J. W. JANUS.

6372. "The stereochemistry of triarylstibines. Synthesis and optical resolution of *p*-carboxyphenyl-2-diphenylylphenylstibine." By I. G. M. CAMPBELL.

6373. "The preparation and stability of alkyl dichloroboronites." By W. GERRARD and M. F. LAPPERT.

6374. "5-Formyl-8-hydroxyquinoline." By G. R. CLEMO and R. HOWE.

6375. "Preparation and some physical properties of sulphur tetrafluoride." By F. BROWN and P. L. ROBINSON.

6376. "Pavine. Part I. The structure and chemistry of pavine." By ALAN R. BATTERSBY and R. BINKS.

6377. "The synthesis of 2′ : 3′ : 2″ : 3″-tetramethoxy-1 : 2-4 : 5-dibenz*ocyclo*hepta-1 : 4-dienes and related compounds." By ALAN R. BATTERSBY and R. BINKS.

6378. "A new application of the theory of corresponding solutions to measurements of the stabilities of some metal complexes." By HARRY IRVING and DEREK H. MELLOR.

6379. "The constitution of gum myrrh. Part II." By J. K. N. JONES and J. R. NUNN.

6381. "Addition of free radicals to unsaturated systems. Part XI. The direction of radical addition to 1 : 1 : 3 : 3 : 3-pentafluoropropene, and the synthesis of perfluoro-olefins, -ketones, and -acids." By R. N. HASZELDINE and B. R. STEELE.

6382. "Compounds formed between hydrogen peroxide and sulphates, selenates, and tellurates in aqueous solution." By S. PANI and (the late) HENRY TERREY.
6383. "Prodigiosin." By E. N. MORGAN and (MISS) E. M. TANNER.
6386. "The products from the high-temperature reaction between silicon tetrachloride and hydrogen sulphide." By D. J. PANCKHURST, C. J. WILKINS, and P. W. CRAIGHEAD.
6387. "Organosilicon compounds. Part XV. Derivatives of α- and γ-picoline." By C. EABORN and R. A. SHAW.
6388. "The reaction between L-cystinebis-3-phenylhydantoin and sodium in liquid ammonia." By L. CROMBIE and K. C. HOOPER.
6391. "Perfluoroalkyl derivatives of sulphur. Part II. Trifluoromethane-sulphonic, -sulphinic, and -sulphenic acids and the infrared spectra of compounds containing $-SO_2-$ and $>S{:}O$ groups." By R. N. HASZELDINE and J. M. KIDD.
6394. "The constitution of the starch from malted barley." By G. O. ASPINALL, E. L. HIRST, and W. MCARTHUR.
6395. "Quinoxalines and related compounds. Part II. The preparation of *NN'*-di-methyl-*o*-phenylenediamine and *N*-methyl-*o*-phenylenediamine." By G. W. H. CHEESEMAN.
6398. "Acylation and allied reactions catalysed by strong acids. Part XIV. Some reactions of the α-chlorodiphenylmethyl ($^+CPh_2Cl$) and *p*-methoxytriphenylmethyl cations." By H. BURTON and G. W. H. CHEESEMAN.
6401. "The cyclisation of 1 : 4- and 1 : 5-di-(α-anthraquinonylamino)anthraquinones to derivatives of carbazole." By WILLIAM BRADLEY and P. N. PANDIT.
6402. "The synthesis and antibacterial activity of some basic derivatives of the bile acids." By MARJORIE L. HILTON, A. S. JONES, and J. R. B. WESTWOOD.
6403. "The synthesis of (±)-apiose and (±)-cordycepose." By R. A. RAPHAEL and C. M. ROXBURGH.
6406. "Mass-law and ionic-strength effects in the hydrolysis of diphenyldichloromethane." By B. BENSLEY and G. KOHNSTAM.
6408. "Reactions of organic peroxides. Part VII. Reaction of 1-hydroxy*cyclo*alkyl hydroperoxides with ferrous compounds." By E. G. E. HAWKINS.
6409. "Autoxidation of αβ-unsaturated ketones." By E. G. E. HAWKINS.
6413. "Friedel–Crafts reactions with methyl *m*-tolyl ether." By J. F. MIQUEL, Ng. PH. BUU-HOÏ, and RENÉ ROYER.
6414. "Studies in the steroid group. Part LXX. Reactions at $C_{(11)}$ in 9β-steroids." By A. CRAWSHAW, H. B. HENBEST, E. R. H. JONES, and A. A. WAGLAND.
6415. "Aryl-2-halogenoalkylamines. Part XV. Some cationic and basically substituted aryl compounds." By F. BERGEL, J. L. EVERETT, J. J. ROBERTS, and W. C. J. ROSS.
6419. "Adsorption of insoluble vapours on water surfaces. Part I." By C. L. CUTTING and D. C. JONES.
6421. "The reaction of chlorodimethyl ether with ethanol and with ethoxide ions." By P. BALLINGER, P. B. D. DE LA MARE, G. KOHNSTAM, and B. M. PRESTT.
6422. "Heterocyclic systems related to pyrrocoline. Part I. 2 : 3*a*-Diazaindene." By J. D. BOWER and G. R. RAMAGE.
6431. "The reactions of potassium nitrorhodate(III) and potassium nitroiridate(III) with potassium hydrogen fluoride." By R. D. PEACOCK.
6433. "Lycorine anhydromethine." By T. SHINGU, S. UYEO, and H. YAJIMA.
6439. "Experiments on the synthesis of *Bz*-substituted indoles and tryptophans. Part III. The synthesis of the four *Bz*-chloro-indoles and -tryptophans." By H. N. RYDON and J. C. TWEDDLE.
6442. "Protection of the ethynyl group during reduction." By N. A. DOBSON and R. A. RAPHAEL.
6446. "Some chlorinated hydroxyphenoxyacetic acids." By J. P. BROWN and E. B. MCCALL.
6448. "Partial reduction of steroid hormones and related substances." By J. K. NORYMBERSKI and GILBERT F. WOODS.
6449. "The reaction of diazonium salts with α-aceto-γ-lactones." By G. F. DUFFIN and J. D. KENDALL.

PROCEEDINGS

OF THE

CHEMICAL SOCIETY

SCIENTIFIC MEETINGS DURING OCTOBER, 1955

LONDON.

Thursday, October 20th, 1955, at 7.30 p.m.

Centenary Lecture, **The Photosynthetic Carbon Cycle,** by Professor M. Calvin, Ph.D. To be given in the Rooms of the Society, Burlington House, W.1.

ABERDEEN.

Friday, October 28th, 1955, at 7.30 p.m.

Lecture, **Electron Transfer Reactions,** by Professor C. E. H. Bawn, Ph.D., F.R.S. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry, to be held at Marischal College.

BIRMINGHAM.

Friday, October 14th, 1955, at 4.30 p.m.

Lecture, **New Aspects of Aromatic Character,** by Professor Wilson Baker, D.Sc., F.R.S. Joint Meeting with Birmingham University Chemical Society, to be held in the Chemistry Department, The University.

Monday, October 24th, 1955, at 4.30 p.m.

Centenary Lecture, **The Photosynthetic Carbon Cycle,** by Professor M. Calvin, Ph.D. To be given in the Chemistry Department, The University.

BRISTOL.

Thursday, October 6th, 1955, at 7 p.m.

Lecture. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry, to be held in the Department of Chemistry, The University.

Wednesday, October 19th, 1955, at 6.30 p.m.

Lecture, **Some Newer Plastic Materials,** by Dr. E. M. Evans, B.Sc., A.R.C.S., A.R.I.C. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry, to be held at The Technical College, Brunswick Road, Gloucester.

Thursday, October 20th, 1955, at 7 p.m.

Lecture, **Organic Inclusion Compounds and their Uses,** by Professor Wilson Baker, D.Sc., F.R.S. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry, to be held in the Department of Chemistry, The University.

Thursday, October 27th, 1955, at 5.15 p.m.

Lecture, **Some Properties of Aqueous Hydrogen Fluoride Solutions,** by Mr. R. P. Bell, M.A., F.R.S. Joint Meeting with Student Chemical Society, to be held in the Department of Chemistry, The University.

CAMBRIDGE.

Friday, October 21st, 1955, at 8.30 p.m.

Lecture, **Homolytic Aromatic Substitution,** by Professor D. H. Hey, Ph.D., D.Sc., F.R.I.C., F.R.S. Joint Meeting with the University Chemical Society, to be held in the Chemical Laboratory, Pembroke Street, Cambridge.

EDINBURGH.

Thursday, October 6th, 1955, at 7.30 p.m.

Society of Chemical Industry Lister Memorial Lecture, **The Chemistry and Functions of Vitamin B_{12},** by Dr. E. Lester Smith, F.R.I.C. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry. To be held at the North British Station Hotel.

Thursday, October 20th, 1955, at 7.30 p.m.

Lecture, **Some Fatty Acids of Recent Description,** by Dr. F. D. Gunstone, B.Sc. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry, to be held at the North British Station Hotel.

IRISH REPUBLIC.

Friday, October 28th, 1955, at 7.45 p.m.

Lecture, **Phenylation,** by Professor D. H. Hey, Ph.D., D.Sc., F.R.I.C., F.R.S. Joint Meeting with the Werner Society, to be held at Trinity College, Dublin.

LEEDS.

Thursday, October 13th, 1955, at 5.0 p.m.

Lecture, **The Mechanism of the Liquid-phase Oxidation of Decane,** by Dr. G. H. Twigg, B.Sc. Joint Meeting with the Royal Institute of Chemistry, the Society of Chemical Industry, the British Association of Chemists, and the University Chemical Society, to be held in the Chemistry Lecture Theatre, The University.

Monday, October 31st, 1955, at 6.30 p.m.

Lecture, **The Hydrogen Isotope Effect in Reaction Kinetics,** by Mr. R. P. Bell, M.A., F.R.S. To be given in the Chemistry Lecture Theatre, The University.

MANCHESTER.

Wednesday, October 5th, 1955, at 6.30 p.m.

Lecture, **Inorganic Metallurgical Aspects of Atomic Energy,** by Mr. L. Rotheram, M.Sc. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry, to be held in the Large Chemistry Theatre, The University.

NEWCASTLE AND DURHAM.

Monday, October 17th, 1955, at 5.15 p.m.

Lecture, **New Aspects of Aromatic Character,** by Professor Wilson Baker, M.A., Ph.D., D.Sc., F.R.I.C., F.R.S. Joint Meeting with the Durham Colleges Chemical Society, to be held in the Science Laboratories, South Road, Durham.

Wednesday, October 26th, 1955, at 5.30 p.m.

Bedson Club Lecture, **The Photosynthetic Carbon Cycle**, by Professor M. Calvin, Ph.D. To be given in the Chemistry Building, King's College, Newcastle-on-Tyne, 1. (All Fellows are invited.)

Monday, October 31st, 1955, at 5.15 p.m.

Lecture, **Recent Researches on the Metal Alkoxides,** by Professor W. Wardlaw, C.B.E., D.Sc., F.R.I.C. Joint Meeting with the Durham Colleges Chemical Society, to be held in the Science Laboratories, South Road, Durham.

NORTHERN IRELAND.

Thursday, October 20th, 1955, at 7.15 p.m.

Lecture, **Silicones, Their Chemistry and Technology,** by Dr. G. G. Freeman, F.R.I.C. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry, to be held at Queen's University, Belfast.

NOTTINGHAM.

Monday, October 17th, 1955, at 4.30 p.m.

Lecture, **Hydrogen Transfer Reactions,** by Professor E. A. Braude, Ph.D., A.R.C.S. Joint Meeting with the University College, Leicester, Chemical Society, to be held at University College, Leicester.

OXFORD.

Monday, October 24th, 1955, at 8.15 p.m.

Lecture, **Hormones Which Stimulate Growth,** by Professor F. G. Young, Ph.D., D.Sc., F.R.I.C., F.R.S. Joint Meeting with the Oxford University Alembic Club, to be held in the Physical Chemistry Laboratory, South Parks Road, Oxford.

SHEFFIELD.

Thursday, October 27th, 1955, at 7.30 p.m.

Lecture, **Chemical Effects of Intramolecular Strains,** by Dr. G. Baddeley. Joint Meeting with Sheffield University Chemical Society, to be held in the Department of Chemistry, The University.

SOUTHAMPTON.

Friday, October 14th, 1955, at 5.0 p.m.

Lecture, **Recent Developments in Acetylene and Allene Chemistry,** Professor E. R. H. Jones, Ph.D., D.Sc., F.R.I.C., F.R.S. Joint Meeting with Southampton University Chemical Society and the Royal Institute of Chemistry, to be held in the Chemistry Department, The University.

SOUTH WALES.

Monday, October 24th, 1955, at 5.30 p.m.

Lecture, **Trapped Radicals in Polymerisation Reactions,** by Dr. C. H. Bamford, M.A., A.R.I.C. To be given in the Chemistry Department, University College, Cardiff.

OFFICIAL ANNOUNCEMENTS

DEATHS.

The Council regrets to announce the deaths of the following Fellows:

	Elected.	Died.
Michael Frederick Fletcher (Cheltenham)	May 12th, 1949.	May 29th, 1955.
Bernhard Flurscheim (Fleet)	July 5th, 1906.	June 15th, 1955.
Osman Jones (London, E.C.1)	May 18th, 1944.	June 22nd, 1955.
Robert Henry Aders Plimmer (London, S.W.15) (C. 1914—18; 1930—33)	June 15th, 1899.	June 18th, 1955.
Humphrey Rivaz Raikes (Johannesburg)	Dec. 6th, 1917.	April 13th, 1955.
Wallace Frank Short (Nottingham)	Dec. 4th, 1919.	June 7th, 1955.

ACKNOWLEDGMENT.

Acknowledgment is made of a gift of the Society's publications from Mr. E. V. Elwes.

ELECTION OF NEW FELLOWS.

The following 30 candidates were elected Fellows of the Society on August 15th, 1955:

Arthur Clinton Andrews.
Nwaeze Anyanwu.
Lewis Maurice Berkowitz.
Keith Jasper Clark.
Noel Hugh Davies.
Rajendra Lal De.
John Barker Downes.
Robert Arthur Edge.
John Dennis Few.
James Wotherspoon Fisher.
Eric Walter Hammond.
Norman David Haworth.
Frank Leroy Holloway.
Enid Gillian Holmes.
Wei-Hwa Hsu.
Brian John Russell Laundy.
Bernard J. Ludwig.
Frank John Masuelli.
Malcolm George Palmer.
Prem Nath Pandit.
Arthur Hamilton Poulson.
David Bernard Ratcliffe.
Frank Lewis Riley.
John Shavel, jun.
Ernest Sherwin.
James Edward Stanfield.
Jessie Irene Turner.
Kenneth Turner.
Neil Russell Williams.
Paul Witherington.

CHEMICAL SOCIETY LIBRARY REORGANISATION.

During the summer closure very extensive alterations have been made to the library.

Some 12,000 volumes have been housed in a new store in Savile Row. The entire periodical stock has been moved around within Burlington House, in part to new storage space, in part within the library rooms to provide adequate room for expansion and to bring more periodicals within the direct access of readers. This has necessitated the removal and replacement of some 60,000 volumes. It is therefore inevitable that there will be some dislocation of services and records for some time to come, but every effort is being made to cut this to a minimum.

The rearrangement of the books provides for the following:

The main library houses modern text-books and essential reference works. The older text-books are being transferred to store.

The back library houses the last fifteen years of the major chemical periodicals.

In each case these works have been kept to the lower shelves, and the upper shelves in both main and back library have been treated as storage space and now house certain major periodicals prior to 1940.

It is hoped that these arrangements will enable readers to browse more freely at the shelves and to have a speedier service generally.

The books housed in Savile Row are largely little-used periodicals, and it will not be possible to obtain these in less than twenty minutes. This material cannot be obtained in the evenings or on Saturdays. If available, it will, however, be despatched on loan within twenty-four hours of a request being received.

RESEARCH FUND.

A meeting of the Research Fund Committee will be held in November next. All persons who have received grants, and whose accounts have not been declared closed by the Council, are informed that reports must be received by the Society not later than November 1st, 1955.

Applications for grants, to be made on forms available from the General Secretary, must be received on or before November 15th, 1955. Applications from Fellows will receive prior consideration.

Attention is drawn to the fact that the income arising from the donation of the Worshipful Company of Goldsmiths is principally devoted to the encouragement of research in inorganic and metallurgical chemistry and that the income from the Perkin Memorial Fund is to be applied to investigations relating to problems connected with coal-tar and allied industries.

LIST OF APPLICATIONS FOR FELLOWSHIP

(Fellows wishing to lodge objection to the election of these candidates should communicate with the Honorary Secretaries within ten days of the date of publication of the Journal *for August, 1955. Such objections will be treated as confidential. The forms of application are available in the Library.)*

Allen, Peter Edward Marshall, B.Sc. and Ph.D. (Birm.) British. Chemistry Department, The University, Birmingham, 15. Lecturer. *Signed by:* J. C. Robb, J. C. Bevington.

Clendinning, Robert Andrew, B.S. (Union Coll.) American. Walker Laboratory, Rensselaer Polytechnic Institute, Troy, New York, U.S.A. Graduate Student-Teaching Assistant. *Signed by:* H. F. Herbrandson, G. J. Janz.

Duckworth, Martin Ward, B.Sc. (S'ton.) British. Officers Mess, R.A.F., Melksham, Wiltshire. National Service. *Signed by:* K. R. Webb, A. C. Riddiford.

Harrison, Albert Joseph, B.Sc. (Manc.) British. 8, Royalthorn Road, Benehill, Wythenshawe, Manchester, 22. Research Student. *Signed by:* W. C. E. Higginson, G. R. Barker.

Hayden, Donald Geoffrey, Ph.C. British. 105, Bridge Road, Oulton Broad, Lowestoft, Suffolk. Pharmacy and Biochemical Analyst. *Signed by:* V. Askam, L. K. Sharp.

Holmes-Siedle, Andrew Gordon, B.A. (T.C.D.) British. University Chemical Laboratories, Cambridge. Research Student. *Signed by:* B. C. Saunders, B. M. Roberts.

Hulett, John Roger, M.A. and D.Phil. (Oxon.) British. 32, Parkside Drive, Watford, Herts. National Service. *Signed by:* L. A. K. Staveley, L. E. Sutton.

Livingstone, Robert, B.Sc. and Ph.D. (Manc.) British. 24, Alexander Grove, Burnley, Lancs. Lecturer at Burnley Municipal College. *Signed by:* M. C. Whiting, A. E. Wales.

McLean, Stewart, B.Sc. (Glas.) British. Baker Laboratory, Cornell University, Ithaca, N.Y., U.S.A. Graduate Student. *Signed by:* J. Meinwald, D. D. Phillips, J. Ouderkirk.

Osborne, Brian Percival. British. 24, Pleasant Road, Milton, Portsmouth, Hants. Student. *Signed by:* N. B. Chapman, M. C. R. Symons.

Palmer, Peter John, B.Sc. (Lond.) British. 50, Tranmere Road, Whitton, Twickenham, Middlesex. Organic Research Chemist. *Signed by:* R. J. Smith, F. F. Stephens.

Partington, Frederick Laurence, B.Sc. (Sheffield). British. Bispham Hall Farm, Billinge, Nr. Wigan, Lancs. National Service. *Signed by:* B. F. Hallam, M. J. G. Williams.

Pimlott, Paula Jane Elizabeth. British. Somerville College, Oxford. Undergraduate. *Signed by:* L. A. K. Staveley, L. P. Walls.

Seaman, Charles Ernest, B.Sc. and Ph.D. (Leeds). British. Craigmore, Kinder Road, Hayfield, Via Stockport, Cheshire. Senior Lecturer in Chemistry at the Royal Technical College, Salford. *Signed by:* K. S. W. Sing, G. R. Barker.

Southwart, David William, B.Sc. (Manc.) British. 66, Goosemoor Lane, Erdington, Birmingham, 23. Research Chemist at Dunlop Rubber Co. Ltd. *Signed by:* W. C. Davey, W. H. T. Davison.

Sumimoto, Masasi, B.Agric. (Kyushu). Japanese. Forest Institute, Department of Agriculture, University of Kagosima, Kamiacata-cho, Kagoshima, Japan. Lecturer. *Signed by:* S. Shibata, S. Sugasawa.

Sutcliffe, Malcolm Leslie, B.Sc. (Manc.) British. 4, Royle Green Road, Northenden, Manchester. Research Student. *Signed by:* G. R. Barker, K. R. Farrar.

Thompson, James Layland, B.A. (Queen's Univ., Kingston). Canadian. Chemistry Department, Queen's University, Kingston, Ontario, Canada. Student. *Signed by:* J. K. N. Jones, T. J. Painter.

Westlake, Alan Henry. British. 2, Virginia Gardens, Barkingside, Ilford, Essex. Student at Southampton University. *Signed by:* N. B. Chapman, M. C. R. Symons.

Wilkinson, Lionel, A.R.I.C. British. 93, Lumb Lane, Audenshaw, Manchester. Industrial Chemist. *Signed by:* P. J. Coope, K. S. W. Sing.

Yen, Teh Fu, M.S. (West Virginia). Chinese. Box No. 6373, Va. Tech. Station, Blacksburg, Virginia, U.S.A. Research Fellow at Virginia Polytechnic Institute. *Signed by:* L. K. Brice, D. C. Iffland, P. E. Newallis.

UNDER SPECIAL PROVISION APPERTAINING TO CANDIDATES RESIDENT ABROAD.

Balasubramanian, Sithamalli Kothandarama, M.Sc. (Delhi). Indian. Department of Chemistry, University of Delhi, Delhi-8, India. Research Assistant. *Signed by:* T. R. Seshadri.

Bannerjee, Nikhil Ranjan, M.Sc. and Ph.D. (Delhi). Indian. 107/3 I.R.C.A. Quarters, Minto Road, New Delhi-1, India. Research Chemist at Delhi University. *Signed by:* T. R. Seshadri.

Brescia, Frank, B.S. (City College of New York), M.A. and Ph.D. (Columbia). American. The City College, Chemistry Department, New York 31, N.Y., U.S.A. Associate Professor. *Signed by:* K. Mislow.

Burnell Robert Henry,, B.Sc. (Montreal), Ph.D. (New Brunswick). British. Department of Chemistry, University of New Brunswick, Fredericton, New Brunswick, Canada. Graduate Student. *Signed by:* W. I. Taylor.

Noble, Paul, jun., A.B. (Reed College), Ph.D. (Rochester). American. 41 Arbuelo Way, Los Altos, California, U.S.A. Research Chemist with Arthur D. Little, Inc., San Francisco. *Signed by:* D. S. Tarbell.

PAPERS ACCEPTED

(List of Papers accepted between June 28th and July 27th, 1955, for publication in the *Journal*.)

Numbers quoted are "Reprint Order Numbers." Reprints may be ordered from the list below, or from the published *Journal* (January 1954, onwards). Orders must be sent to the General Secretary accompanied by a remittance for 5*s*. for each reprint or by the appropriate number of reprint vouchers.

6292. "Hydrogen electrode processes. Part I. Platinum hydrogen electrodes." By R. H. COUSENS, D. J. G. IVES, and S. SWAROOPA.

6293. "Hydrogen electrode processes. Part II. Gold–hydrogen electrodes." By D. J. G. IVES and S. SWAROOPA.

6317. "The salting-out of non-electrolytes. Part III. The inert gases and sulphur hexafluoride." By T. J. MORRISON and N. B. B. JOHNSTONE.

6327. "Exchange reactions of solid oxides. Part VII. Cr_2O_3, NiO, and Fe_2O_3." By E. R. S. WINTER.

6329. "The oxides of uranium. Part VI. The chemisorption of reducing gases on uranium and thorium dioxides." By L. E. J. ROBERTS.

6330. "The oxides of uranium. Part VII. The oxidation of uranium dioxide." By J. S. ANDERSON, L. E. J. ROBERTS, and E. A. HARPER.

6345. "Partial molar quantities at infinite dilution in dissociating solvents." By P. A. H. WYATT.

6360. "The kinetics of hydrogen isotope exchange reactions. Part II There action between *p*-substituted [*o*-^{2}H]phenols and aqueous sulphuric acid." By V. GOLD and D. P. N. SATCHELL.

6361. "The kinetics of hydrogen isotope exchange reactions. Part III. The reaction between [$^2H_1$]benzene and aqueous sulphuric acid." By V. GOLD and D. P. N. SATCHELL.

6362. "The kinetics of hydrogen isotope exchange reaction. Part IV. A comparison of the exchange reactivity of different aqueous acids." By V. GOLD and D. P. N. SATCHELL.

6369. "The molecular polarisation and association of some hydroxylic compounds in benzene solution." By (the late) A. H. BOUD, D. CLEVERDON, G. B. COLLINS, and J. W. SMITH.

6384. "The nature of the internal hydrogen bond. Part II. Electronic spectra of 2-nitrosoanisole and 6-methoxyimino*cyclo*hexa-2 : 4-dienone and their derivatives." By A. BURAWOY, M. CAIS, J. T. CHAMBERLAIN, F. LIVERSEDGE, and A. R. THOMPSON.

6385. "The nature of the internal hydrogen bond. Part III. Tautomeric equilibria of 2-nitrosophenols." By A. BURAWOY, M. CAIS, J. T. CHAMBERLAIN, F. LIVERSEDGE, and A. R. THOMPSON.

6389. "Chlorophyll and related substances. Part I. The synthesis of chlorin." By ULLI EISNER and R. P. LINSTEAD.

6390. "Chlorophyll and related substances. Part II. The dehydrogenation of chlorin to porphin and the number of extra hydrogens in the chlorins." By ULLI EISNER and R. P. LINSTEAD.

6393. "The kinetics of alkyl–oxygen fission in ester hydrolysis. Part IV. *tert.*-Butyl formate in aqueous acetone." By V. R. STIMSON.

6400. "Paper chromatography of uronic acids." By R. A. EDINGTON and ELIZABETH PERCIVAL.

6404. "Precise measurements with the glass electrode. Part I. The cell: glass electrode|HCl|AgCl|Ag." By A. K. COVINGTON and J. E. PRUE.

6405. "Precise measurements with the glass electrode." Part II. The cell: glass electrode|HCl(m_1)|HCl(m_2)|glass electrode." By A. K. COVINGTON and J. E. PRUE.

6412. "The infrared spectra of some compounds containing the pentacyanoferrate group." By E. F. G. HERINGTON and W. KYNASTON.

6417. "The characteristic infrared absorption of the methyl rocking vibrations of aromatic methyl groups." By R. R. RANDLE and D. H. WHIFFEN.

6420. "The cryoscopic behaviour of polynitro-compounds in sulphuric acid." By J. R. BRAYFORD and P. A. H. WYATT.

6423. "Studies in light absorption. Part XI. Substituted benzaldehydes, acetophenones, and related compounds. The effects of steric conformation on the electronic spectra of conjugated systems." By E. A. BRAUDE and F. SONDHEIMER.

6424. "Studies in light absorption. Part XII. The effects of steric conformation on the ultraviolet and infrared spectra of alicyclic ethylenic ketones." By E. A. BRAUDE and C. J. TIMMONS.

6425. "Studies in light absorption. Part XIII. Steric effects in *ortho*-substituted styryl and related derivatives." By E. A. BRAUDE and F. SONDHEIMER.

6426. "Studies in light absorption. Part XIV. Steric effects in *ortho*-substituted diphenyls." By E. A. BRAUDE and W. F. FORBES.

6428 "Preparation and polymerisation of some 3 : 3-disubstituted oxa*cyclo*butanes." By A. C. FARTHING.

6434. "The preparation of active solids by thermal decomposition. Part VII. The calcination of (*a*) ion-free, (*b*) sulphate-contaminated, precipitated alumina hydrates." By S. J. GREGG and K. H. WHEATLEY.

6435. "Sugar nitrates. Part II. The preparation and reactions of some nitrates, sulphates, sulphinates, and other esters of methyl 4 : 6-*O*-benzylidene-α-D-glucoside." By JOHN HONEYMAN and J. W. W. MORGAN.

6436. "An investigation of complex formation by partition of a reactant between the vapour phase and solution: the determination of association constants and the heats of formation of some hydrogen bonds." By R. L. DENYER, A. GILCHRIST, J. A. PEGG, J. SMITH, T. E. TOMLINSON, and L. E. SUTTON.

6437. "The electric dipole moments of some hydrogen-bonded complexes." By J. R. HULETT, J. A. PEGG, and L. E. SUTTON.

6444. "The chlorination of 2-acetamidofluorene." By F. BELL and J. A. GIBSON.

6445. "The polarisation of azobenzene as a vapour." By H. C. FREEMAN, R. J. W. LE FÈVRE, D. A. A. S. NARAYANA RAO, and I. G. ROSS.

6447. "The stabilities of metal chelate compounds formed by some heterocyclic acids. Part II. Studies in aqueous dioxan." By F. HOLMES and W. R. C. CRIMMIN.

6451. "Studies of *Aspergillus niger*. Part IV. The synthesis of β-linked glucosaccharides." By S. A. BARKER, E. J. BOURNE, G. C. HEWITT, and M. STACEY.

6452. "The preparation and properties of some plutonium compounds. Part I. Plutonium hydride." By F. BROWN, HEATHER M. OCKENDEN, and G. A. WELCH.

6454. "1 : 1-Diethylsulphonyl derivatives of L-rhamnose and their conversion into 5-deoxy-L-arabinose." By L. HOUGH and T. J. TAYLOR.

6455. "The condensation of phenols with nitrobenzaldehydes." By J. E. DRIVER and (MISS) S. F. MOK.

6456. "Hydroxycarbazoles and tetrahydrohydroxycarbazoles. Part III." By JOSÉ A. CUMMINS and MURIEL L. TOMLINSON.

6457. "Tetracarbonyliron *bis*phenylacetylide." By E. R. H. JONES, P. C. WAILES, and M. C. WHITING.

6460. "Perfluoroalkyl derivatives of sulphur. Part III. Some reactions of trifluoromethanethiol, and the spectroscopic properties of the >C:S group." By R. N. HASZELDINE and J. M. KIDD.

6462. "The diamagnetic susceptibilities of some oximes and oxime ethers." By C. M. FRENCH and D. HARRISON.

6468. "*N*-Hydroxy-imides. Part II. Derivatives of homophthalic and phthalic acids." By D. E. AMES and T. F. GREY.

6469. "Intervention of polyhalides in thionyl bromide–alcohol systems." By M. J. FRAZER and W. GERRARD.

6474. "Organosilicon compounds. Part XVI. The alkaline hydrolysis of triorganomonosilanes." By J. E. BAINES and C. EABORN.

6478. "A novel method of cyanoethylation. Part III. The mechanism of the reaction." By J. CYMERMAN-CRAIG, M. MOYLE, A. J. C. NICHOLSON, and R. L. WERNER.

6484. "The synthesis of sugars from simpler substances. Part IX. The enzymic synthesis of 5 : 6-dideoxy-D-*threo*hexulose." P. A. J. GORIN, L. HOUGH, and J. K. N. JONES.

6486. "Pyrimidines. Part VIII. Halogeno- and hydrazino-pyrimidines." By J. CHESTERFIELD, J. F. W. MCOMIE, and E. R. SAYER.

6488. "Absorption of insoluble vapours on water surfaces. Part II." By D. C. JONES and R. H. OTTEWILL.

6489. "Homolytic aromatic substitution. Part X. The phenylation of pyridine." By D. H. HEY, C. J. M. STIRLING, and GARETH H. WILLIAMS.

6495. "Reactions with Girard reagents." By ALEXANDER MACKIE and ANAND L. MISRA.

6496. "Reaction of potassium bromide–bromate solution with some sulphur compounds." By F. W. SHIPLEY.

6507. "Esters containing phosphorus. Part XIII. Dialkyl phosphorobromidates." By H. GOLDWHITE and B. C. SAUNDERS.

6509. "The nitration of *o*-fluorotoluene." By H. SUSCHITZKY.

6512. "Fluoro-olefins. Part III. Some rearrangement reactions of polyhalogeno-olefins and routes to butadienes." By R. N. HASZELDINE and J. E. OSBORNE.

6519. "Palladium(0) compounds. Part I. Di*iso*nitrilopalladium(0) compounds." By LAMBERTO MALATESTA.

6522. "Decomposition of quinaldinic and *meso*benzanthrone-3-carboxylic acids in the presence of *meso*benzanthrone." By WILLIAM BRADLEY and HARRY E. NURSTEN.

PROCEEDINGS

OF THE

CHEMICAL SOCIETY

SCIENTIFIC MEETINGS

CORRECTION

Thursday, October 20th, 1955, at 7.30 p.m.

The Centenary Lecture entitled **The Photosynthetic Carbon Cycle,** by Professor M. Calvin, Ph.D., will be given in the Lecture Theatre of the Institution of Civil Engineers, Gt. George Street, London, W.1, and not at Burlington House, as stated in the Proceedings for August, 1955.

SCIENTIFIC MEETINGS DURING NOVEMBER, 1955

LONDON.

Thursday, November 3rd, 1955, at 7.30 p.m.

Meeting for the Reading of Original Papers. To be held in the Rooms of the Society, Burlington House, W.1.

Thursday, November 17th, 1955, at 7.30 p.m.

Tilden Lecture, **Some Developments in the Study of Physical Adsorption,** by Professor D. H. Everett, M.B.E., M.A., D.Phil. To be given in the Large Chemistry Lecture Theatre, Imperial College of Science and Technology, South Kensington, S.W.7.

ABERDEEN.

Thursday, November 24th, 1955, at 7.45 p.m.

Liversidge Lecture, **Reactions of Radicals in Gaseous Systems,** by Dr. E. W. R. Steacie, O.B.E., D.Sc., F.R.S. Joint Meeting with The Royal Institute of Chemistry and the Society of Chemical Industry, to be held in the University Chemistry Department, Old Aberdeen.

BIRMINGHAM.

Friday, November 18th, 1955, at 4.30 p.m.

Lecture, **The Interpretation of Electromotive-force Measurements with Special Reference to the Gastric Mucosa,** by Dr. A. G. Ogston, F.R.S. Joint Meeting with Birmingham University Chemical Society, to be held in the Chemistry Department, The University.

BRISTOL.

Thursday, November 3rd, 1955, at 7 p.m.

Lecture, **New Aspects of the Chemistry of the Nitrogen Oxides,** by Dr. C. C. Addison, F.R.I.C. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry, to be held in the Chemistry Department, The University.

Thursday, November 10th, 1955, at 5.15 p.m.

Lecture, **The Problems Involved in Studying Fast Reactions,** by Professor H. W. Melville, D.Sc., F.R.I.C., F.R.S. Joint Meeting with the Student Chemical Society, to be held in the Chemistry Department, The University.

Thursday, November 17th, 1955, at 7 p.m.

Lecture, **Principles of Crystal Growth,** by Professor F. C. Frank, F.R.S. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry, to be held in the Chemistry Department, The University.

Thursday, November 24th, 1955, at 5.15 p.m.

Lecture, **Magnetism and the Shape of Inorganic Molecules,** by Professor R. S. Nyholm, D.Sc., A.R.I.C. Joint Meeting with the Student Chemical Society, to be held in the Chemistry Department, The University.

CAMBRIDGE.

Friday, November 4th, 1955, at 8.30 p.m.

Lecture, **Synthetic Polypeptides,** by Dr. C. H. Bamford, M.A., A.R.I.C. Joint Meeting with the University Chemical Society, to be held in the University Chemical Laboratory, Pembroke Street, Cambridge.

Friday, November 18th, 1955, at 8.30 p.m.

Lecture, **Many-centre Bonds,** by Professor H. C. Longuet-Higgins, M.A. Joint Meeting with the University Chemical Society, to be held in the University Chemical Laboratory, Pembroke Street, Cambridge.

EDINBURGH.

Thursday, November 10th, 1955, at 7.30 p.m.

Lecture, **Hydrogen-transfer Reactions,** by Professor E. A. Braude, Ph.D., D.Sc., F.R.I.C. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry, to be held at the North British Station Hotel.

GLASGOW.

Friday, November 18th, 1955, at 7.15 p.m.

Lecture, **Solid Imperfections and Chemical Reactivity,** by Dr. F. Ç. Tompkins, F.R.S. To be given in the Chemistry Department, The University.

HULL.

Thursday, November 24th, 1955, at 6.30 p.m.

Lecture by Professor W. Bradley, M.Sc., Ph.D., F.R.I.C. Joint Meeting with the Royal Institute of Chemistry, to be held in the Chemistry Department, The University.

IRISH REPUBLIC.

Wednesday, November 30th, 1955, at 7.45 p.m.

Lecture, **Properties of Periodate-oxidised Polysaccharides,** by Dr. V. C. Barry, F.R.I.C., F.I.C.I., M.R.I.A. To be given at Trinity College, Dublin.

LEEDS.

Monday, November 7th, 1955, at 6.30 p.m.

Royal Institute of Chemistry Lecture, **Antibiotics—Past, Present, and Future,** by Mr. A. L. Bacharach, M.A., F.R.I.C. To be given in the Chemistry Lecture Theatre, The University. (All Fellows are invited.)

Thursday, November 17th, 1955, at 6.30 p.m.

Liversidge Lecture, **Reactions of Radicals in Gaseous Systems,** by Dr. E. W. R. Steacie, O.B.E., M.Sc., F.R.S. To be given in the Chemistry Lecture Theatre, The University.

LIVERPOOL.

Thursday, November 10th, 1955, at 5 p.m.

Lecture, **The Chromatography of Gases and Vapours,** by Dr. F. H. Pollard, B.Sc., A.R.I.C. Joint Meeting with the Royal Institute of Chemistry, the Society of Chemical Industry, the British Association of Chemists, and the University Chemical Society. To be held in the Chemistry Lecture Theatre, The University.

MANCHESTER.

Tuesday, November 1st, 1955, at 6.30 p.m.

Centenary Lecture, **The Photosynthetic Carbon Cycle,** by Professor M. Calvin, Ph.D. To be given in the Large Chemistry Theatre, The University.

Thursday, November 17th, 1955, at 6.30 p.m.

Meeting for the Reading of Original Papers. To be held in the Robinson Theatre, The University.

NEWCASTLE AND DURHAM.

Friday, November 4th, 1955, at 4 p.m.

Meeting for the Reading of Original Papers. To be held in the Chemistry Building, King's College, Newcastle-on-Tyne, 1.

Friday, November 25th, 1955, at 5.30 p.m.

Bedson Club Lecture, **The Relation between Theory and Experiment in Physical Chemistry,** by Professor E. A. Guggenheim, M.A., Sc.D., F.R.S. To be given in the Chemistry Building, King's College, Newcastle-on-Tyne, 1. (All Fellows are invited.)

Monday, November 28th, 1955, at 5.15 p.m.

Lecture, **Some New Results Obtained by the Method of Flash Photolysis,** by Professor R. G. W. Norrish, D.Sc., F.R.I.C., F.R.S. Joint Meeting with the Durham Colleges Chemical Society, to be held in the Science Laboratories, South Road, Durham.

NORTHERN IRELAND.

Tuesday, November 22nd, 1955, at 7.15 p.m.

Lecture, **Preparation and Use of Radio-isotopes in Industry and Medicine,** by Dr. G. B. Cook. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry, to be held at The Queen's University, Belfast.

NORTH WALES.

Thursday, November 10th, 1955, at 5.45 p.m.

Lecture, **Some Experiences in an Industrial Research Laboratory,** by Dr. M. A. T. Rogers, B.Sc., A.R.I.C. Joint Meeting with University of North Wales Chemical Society, to be held in the Chemistry Department, University College of North Wales, Bangor.

NOTTINGHAM.

Thursday, November 3rd, 1955, at 4.30 p.m.

Lecture by Professor C. W. Shoppee, Ph.D., D.Sc., F.R.I.C. Joint Meeting with University College, Leicester, Chemical Society, to be held at University College Leicester.

Thursday, November 10th, 1955, at 4.45 p.m.

Lecture, **New Aspects of Aromatic Character,** by Professor Wilson Baker, D.Sc., F.R.I.C., F.R.S. Joint Meeting with the University of Nottingham Chemical Society, to be held at The University, Nottingham.

Friday, November 25th, at 4.45 p.m.

Lecture, **Recent Advances in the Physical Chemistry of Sulphur,** by Professor G. Gee, Ph.D., A.R.I.C., F.R.S. Joint Meeting with the University of Nottingham Chemical Society, to be held at The University, Nottingham.

OXFORD.

Monday, November 7th, 1955, at 8.15 p.m.

Lecture, **Fluorocarbons—The Basis of a New Chemistry,** by Dr. R. N. Haszeldine, B.Sc. Joint Meeting with the Oxford University Alembic Club, to be held in the Physical Chemistry Laboratory, South Parks Road, Oxford.

Monday, November 28th, 1955, at 8.15 p.m.

Lecture, **Why Polymerisation occurs,** by Professor F. S. Dainton, M.A., Ph.D. Joint Meeting with the Oxford University Alembic Club, to be held in the Physical Chemistry Laboratory, South Parks Road, Oxford.

ST. ANDREWS AND DUNDEE.

Friday, November 18th, 1955, at 5.15 p.m.

Lecture, **The Hydrogen-isotope Effect in Reaction Kinetics,** by Mr. R. P. Bell, M.A., F.R.S. Joint Meeting with the University Chemical Society, to be held in the Chemistry Department, St. Salvators College, St. Andrews.

SHEFFIELD.

Thursday, November 10*th*, 1955, *at* 7.30 *p.m.*

Lecture, **Melting and Crystal Structure,** by Professor A. R. Ubbelohde, M.A., D.Sc., F.R.S. Joint Meeting with the Royal Institute of Chemistry and Sheffield University Chemical Society, to be held in the Department of Chemistry, The University.

SOUTHAMPTON.

Friday, November 25*th*, 1955, *at* 5 *p.m.*

Lecture, **Melting and Crystal Structure,** by Professor A. R. Ubbelohde, M.A., D.Sc., F.R.S. Joint Meeting with Southampton University Chemical Society, to be held in the Chemistry Department, The University.

SOUTH WALES.

Friday, November 4*th*, 1955, *at* 5.30 *p.m.*

Lecture, **The Physical Chemistry of Sulphur,** by Professor G. Gee, Ph.D., A.R.I.C., F.R.S. To be given in the Chemistry Department, University College, Swansea.

OFFICIAL ANNOUNCEMENTS

DEATH.

The Council regrets to announce the death of the following Fellow :

	Elected.	Died.
Philip Rufus Carter (Birmingham)	Mar. 15th, 1945.	June 4th, 1955.

ELECTION OF NEW FELLOWS.

The following 26 candidates were elected Fellows of the Society on September 26th, 1955:

Peter Edward Marshall Allen.
Sithamalli Kothandarama Balasubramanian.
Nikhil Ranjan Bannerjee.
Frank Brescia.
Robert Henry Burnell.
Robert Andrew Clendinning.
Martin Ward Duckworth.
Albert Joseph Harrison.
Donald Geoffrey Hayden.
Andrew Gordon Holmes-Siedle.
John Roger Hulett.
Robert Livingstone.
Stewart McLean.
Paul Noble, Jnr.
Brian Percival Osborne.
Peter John Palmer.
Frederick Laurence Partington.
Paula Jane Elizabeth Pimlott.
Charles Ernest Seaman.
David William Southwart.
Masasi Sumimoto.
Malcolm Leslie Sutcliffe.
James Layland Thompson.
Alan Henry Westlake.
Lionel Wilkinson.
Teh Fu Yen.

RESEARCH FUND.

A meeting of the Research Fund Committee will be held in November next. All persons who have received grants, and whose accounts have not been declared closed by the Council, are informed that reports must be received by the Society not later than November 1st, 1955.

Applications for grants, to be made on forms available from the General Secretary, must be received on or before November 15th, 1955. Applications from Fellows will receive prior consideration.

Attention is drawn to the fact that the income arising from the donation of the Worshipful Company of Goldsmiths is principally devoted to the encouragement of research in inorganic and metallurgical chemistry and that the income from the Perkin Memorial Fund is to be applied to investigations relating to problems connected with coal-tar and allied industries

INTERNATIONAL CONGRESS ON CATALYSIS.

An International Congress on Catalysis will be held in Philadelphia, Pa., from September 10th to 14th, 1956, the purpose of which is to bring together scientists of as many countries and schools of thought as possible to give them an opportunity for an exchange of ideas and opinions. The Congress will have some funds at its disposal and will be able to offer limited financial assistance to invited scientists who would be unable to attend otherwise.

Four major symposia are envisaged, each of which will deal with a variety of subjects :

1. Chemistry and Physics of Solid Catalysts (Catalyst Structure, Electron Transfer Processes in Solids, Poisoning, Reaction Kinetics.)

2. Homogeneous Catalysis and Related Effects (Catalysis by Radicals, Catalysis by Ions, Biocatalysis, Catalysis and Radiation, Photosynthesis.)

3. Surface Chemistry and Its Relation to Catalysis (Corrosion, Flotation, Adsorption, Electrode Processes, Colloids.)

4. Techniques and Technology of Catalysis (Laboratory Techniques for studying Reactions, Catalysis Preparation, Catalytic Reactions of Technological Importance.)

While it is not the objective of the Congress to discuss any of the symposia topics exhaustively, every attempt will be made to bring out the correlation between different catalysts and catalytic phenomena.

All papers on the programme will be circulated in the form of preprints, and brief summaries only will be presented at the meetings to assure maximum opportunity and time for discussion. A few major topics will be presented in more detailed lectures by invited speakers. English, French, and German are the official languages of the Congress.

Prospective contributors are requested to submit the titles and a two-hundred-word abstract for their papers not later than January 1st, 1956. The full paper must be ready for preprinting by March 1st, 1956. All papers submitted for presentation at the Congress will be reviewed by a Committee before acceptance.

It is planned to publish the proceedings of the Congress in book form. Suggestions to authors regarding the form of the papers will be available soon.

Correspondence concerning the programme should be sent to Dr. A. Farkas, Chairman, Programme Committee, International Congress on Catalysis, Barrett Division, Allied Chemical and Dye Corporation, S. Ridgeway Avenue, Glenolden, Pennsylvania. All other communications should be addressed to Dr. H. Heinemann, Executive Secretary, International Congress on Catalysis, c/o Houdry Process Corporation, P.O. Box 427, Marcus Hook, Pennsylvania.

MINUTES OF SCIENTIFIC MEETINGS

Minutes of a

SCIENTIFIC MEETING

held at the University College of the South West of England, Exeter, on July 13th, 14th, and 15th, 1955.

Session 1 on July 13th, at 2.30 p.m.

PROFESSOR R. D. HAWORTH, D.Sc., Ph.D., F.R.S., Vice-President, was in the Chair, and expressed the thanks of the Society to Dr. Schofield for organising the meeting and to the College Authorities for their generous hospitality.

FORMAL ADMISSION OF FELLOWS.

The following were admitted Fellows of the Society: Brian Mills, Roy Hull, J. Chesterfield, J. Harley-Mason, A. N. James, W. S. Lindsay, A. J. Nunn, R. F. Robbins, A. F. Crowther, A. J. Tompsett, T. S. Osdene, A. R. Osborne, D. W. Ockenden, A. Wenham, G. M. Timmis, D. McHale, K. Clarke, R. G. Johnstone, K. Gaimster.

SYMPOSIUM.

Professor Haworth opened the symposium entitled "Recent Work on Naturally Occurring Nitrogen Heterocyclic Compounds." The following contributions were made and discussed:

"Mitragyna Alkaloids," by Dr. J. D. Loudon.

"Synthesis and Biosynthesis in the Indole Alkaloid Field," by Dr. J. Harley-Mason.

"Conessine," by Professor R. D. Haworth.

"Interconversions and Epimerisations of Open and Cyclic Hydroxy-amino-acids," by Dr. B. Witkop.

The meeting then adjourned.

Session 2 on July 14th, at 10 a.m.

DR. J. W. COOK, F.R.S., took the Chair, and welcomed the Society to Exeter. The symposium was resumed and the following contributions were made and discussed :

" The Structure of Chlorophyll : New Analytical and Synthetical Evidence," by Dr. R. P. Linstead.

" The Catalytic Hydrogenation of Porphyrins and of Azaporphyrins," by Dr. M. Whalley.

" The Structure of Vitamin B_{12}," by Sir Alexander Todd, Dr. A. W. Johnson, and Dr. D. C. Hodgkin.

The meeting then adjourned until 2.30 p.m., when PROFESSOR R. D. HAWORTH took the Chair. The following contributions were made and discussed :

" Some Features of the Chemistry of Emetine," by Dr. H. T. Openshaw.

" The Structure and Chemistry of Emetamine," by Dr. A. R. Battersby.

" The Alkaloids of *Gelsemium sempervirens*," by Dr. T. S. Stevens.

" Intermediates in the Biological Synthesis of Purine Nucleotides," by Professor J. Baddiley.

The meeting then adjourned.

Session 3 on July 15th, at 10 a.m.

PROFESSOR J. BADDILEY, D.Sc., Ph.D., was in the Chair. The following contributions were made and discussed :

" Six-membered Heteroaromatic Rings containing Nitrogen : Correlation of Structure and Properties," by Professor A. Albert.

" The Spectra and Structures of some Mono- and Di-cyclic *N*-Heteroaromatic Systems," by Dr. S. F. Mason.

" Mechanism and Kinetics of Nucleophilic Substitution in Nitrogen Heterocyclic Compounds," by Dr. N. B. Chapman.

LIST OF APPLICATIONS FOR FELLOWSHIP

(*Fellows wishing to lodge objection to the election of these candidates should communicate with the Honorary Secretaries within ten days of the date of publication of the* Journal *for September, 1955. Such objections will be treated as confidential. The forms of application are available in the Library.*)

Anderson, Agnes McMillen, B.Sc. (Edin.) British. 34, Gartcows Road, Falkirk, Stirlingshire. Student. *Signed by :* C. B. Wylam, G. O. Aspinall.

Fischback, Bryant Charles, B.S. (California). American. 1324, El Curtola Boulevard, Walnut Creek, California, U.S.A. Research Chemist. *Signed by :* G. H. Harris, M. P. Doerner.

Goodall, David John, B.Pharm. (Lond.), Ph.C., M.P.S. British. 80, Station Road, Broxbourne, Herts. Pharmacist. *Signed by :* R. E. H. Swayne, D. Caldwell.

Gowan, Alastair Campbell. British. Schoolhouse, Banchory, Kincardineshire. Student at Aberdeen University. *Signed by :* A. H. S. Matterson, J. D. M. McConnell.

Laird, Robert McCrone, B.Sc. (Glas.) British. 79, High Road, Saltcoats, Ayrshire. R.A.F. Instrument Mechanic. *Signed by :* S. Horwood Tucker, P. A. Ongley.

Martin, Ralph John. British. 15, Grappenhall Road, Stockton Heath, Warrington, Lancs. Undergraduate at Manchester University. *Signed by :* G. R. Barker, G. D. Meakins.

Mincer, Adam Mieczyslaw Alexander. Polish. 23, Binden Road, London, W.12. Student. *Signed by :* A. T. Lubinski, N. Lewin.

Stephen, Theodora, M.Sc. and Ph.D. (Witwatersrand). South African. 34, Sir Duncan Road, Glenwood, Durban, Natal, South Africa. Temporary Lecturer and Demonstrator at Howard College, Natal University. *Signed by :* F. L. Warren, G. M. Hamilton.

Walshaw, Maurice Vernon, B.Sc. (Lond.), A.R.I.C. British. 177, Rochdale Road, Greetland, Nr. Halifax, Yorks. National Serviceman. *Signed by :* I. T. Smith, J. H. Pierce.

Yates, Peter, M.Sc. (Dalhousie), Ph.D. (Yale). British. Department of Chemistry, Harvard University, Cambridge, Mass., U.S.A. Assistant Professor. *Signed by :* G. H. Stout, D. W. Wiley, R. F. Hutton.

UNDER SPECIAL PROVISION APPERTAINING TO CANDIDATES RESIDENT ABROAD.

Huntsman, William Duane, B.S. (Ohio), Ph.D. (Northwestern). American. 7, North McKinley Street, Athens, Ohio, U.S.A. Associate Professor at Ohio University. *Signed by :* A. G. Brook.

Ingham, Robert Kelly, A.B. (King Coll. Tennessee), Ph.D. (Iowa State Coll.) American. 10, Elmwood Place, Athens, Ohio, U.S.A. Assistant Professor at Ohio University. *Signed by :* A. G. Brook.

Pavanaram, Sripada Kameswara, M.Sc. (Andhra). Indian. Chemistry Department, Andhra University, Waltair, S. India. Research Scholar. *Signed by :* S. Rajagopalan.

PAPERS ACCEPTED

(List of Papers accepted between July 28th and August 26th, 1955, for publication in the *Journal*.)

Numbers quoted are " Reprint Order Numbers." Reprints may be ordered from the list below, or from the published *Journal* (January, 1954, onwards.) Orders must be sent to the General Secretary accompanied by a remittance for 2*s*. for each reprint or by the appropriate number of reprint vouchers.

5759. " Solvent participation in nucleophilic displacement reactions. Part I. General considerations." By R. F. HUDSON and B. SAVILLE.

5760. " Solvent participation in nucleophilic displacement reactions. Part II. The reaction between ethanol and acid chlorides." By R. F. HUDSON and B. SAVILLE.

5761. " Solvent participation in nucleophilic displacement reactions. Part III. Ionisation reactions with particular reference to the alcoholysis of triphenylmethyl chloride." By R. F. HUDSON and B. SAVILLE.

51009. " Mixed liquid crystals. Part II. The effect of structure on the transition temperatures of mixed liquid crystals." By J. S. DAVE and M. J. S. DEWAR.

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Irish Republic.	D. O'Tuama, M.Sc., Ph.D., F.I.C.I., Medical Research Council of Ireland, The Laboratories, Trinity College, Dublin.
Leeds.	E. Rothstein, Ph.D., D.Sc., A.R.C.S., Organic Chemistry Department, The University, Leeds, 2.
Liverpool.	A. K. Holliday, B.Sc., Ph.D., Department of Physical and Inorganic Chemistry, The University, Liverpool.
,,	D. W. Broad, Ph.D., A.R.I.C., Imperial Chemical Industries Limited, Research Department, Widnes Laboratory, Widnes.
Manchester.	G. R. Barker, B.Sc., Ph.D., Chemistry Department, The University, Manchester, 13.
,,	A. C. Farthing, M.A., B.Sc., Imperial Chemical Industries Limited, Hexagon House, Blackley, Manchester, 9.
Newcastle and Durham.	G. A. Swan, D.Sc., Ph.D., F.R.I.C., Department of Chemistry, King's College, Newcastle-on-Tyne, 1.
New Zealand.	Professor S. N. Slater, M.Sc., D.Phil., A.R.I.C., Chemistry Department, Victoria University College, Wellington, New Zealand.
Northern Ireland.	R. G. R. Bacon, PhD., A.R.C.S., Chemistry Department, Queen's University, Belfast.
North Wales.	J. E. McKail, Ph.D., Department of Chemistry, University College of North Wales, Bangor.
Nottingham.	C. C. Addison, D.Sc., Ph.D., F.R.I.C., Chemistry Department, The University, University Park, Nottingham.
Oxford.	L. A. K. Staveley, M.A., Inorganic Chemistry Laboratory, South Parks Road, Oxford.
Pakistan.	M. I. D. Chughtai, M.Sc.Tech., Ph.D., A.R.I.C., Punjab University Institute of Chemistry, The Mall, Lahore, Pakistan.
St. Andrews and Dundee.	C. Horrex, M.Sc., Ph.D., Chemistry Department, The University, St. Andrews.
Sheffield.	H. J. V. Tyrrell, M.A., B.Sc., Chemistry Department, The University, Sheffield, 10.
South Africa.	Professor F. L. Warren, Ph.D., F.R.I.C., Department of Chemistry, University of Natal, P.O. Box 375, Pietermaritzburg, South Africa.
Southampton.	N. B. Chapman, M.A., Ph.D., Department of Chemistry, The University, Southampton.
South Wales.	K. W. Sykes, M.A., B.Sc., D.Phil., Department of Chemistry, University College, Singleton Park, Swansea.

PROCEEDINGS

OF THE

CHEMICAL SOCIETY

SCIENTIFIC MEETINGS DURING DECEMBER, 1955

LONDON.

Thursday, December 1st, 1955, at 7.30 p.m.

Liversidge Lecture, **Reactions of Radicals in Gaseous Systems,** by Dr. E. W. R. Steacie, O.B.E., M.Sc., F.R.S. To be given in the Lecture Theatre, The Royal Institution, Albemarle Street, London, W.1.

Thursday, December 15th, 1955, at 7.30 p.m.

Meeting for the Reading of Original Papers. To be held in the Rooms of the Society, Burlington House, London, W.1.

ABERDEEN.

Friday, December 9th, 1955, at 7.30 p.m.

Lecture, **Some Chemical Aspects of Cell Structure,** by Professor J. N. Davidson, D.Sc., M.D., F.R.S.E. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry, to be held at Marischal College.

BRISTOL.

Thursday, December 1st, 1955, at 7 p.m.

Lecture, **Manufacture of Phosphoric Acid,** by Mr. J. J. Porter. Joint Meeting with the Royal Institute of Chemistry, the Society of Chemical Industry, and the Institute of Metals. To be held in the Chemistry Department, The University.

EDINBURGH.

Thursday, December 8th, 1955, at 7.30 p.m.

Lecture, **Some Aspects of Research in the Scottish Division of the National Coal Board,** by Dr. E. A. C. Chamberlain. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry. To be held at the North British Station Hotel.

GLASGOW.

Friday, December 2nd, 1955, at 7.15 p.m.

Lecture, **Studies of the Molecular Basis of Biological Motility : or how to swim with only a molecule for a tail,** by Professor W. T. Astbury, M.A., Sc.D., F.R.S. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry. To be held at the Royal Technical College.

MANCHESTER.

Thursday, December 1st, 1955, at 6.30 p.m.

Lecture, **Recent Developments in Fungal Biochemistry,** by Dr. J. H. Birkinshaw, F.R.I.C. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry. To be held in the Large Chemistry Theatre, The University.

NORTHERN IRELAND.

Monday, December 5th, 1955, at 7.45 p.m.

Lecture, **Recent Advances in the Vitamin D Field,** by Professor B. Lythgoe, M.A., Ph.D., F.R.I.C. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry. To be held at the Queen's University, Belfast.

NOTTINGHAM.

Thursday, December 1st, 1955, at 4.45 p.m. (Postponed from November 25th.)

Lecture, **Recent Advances in the Physical Chemistry of Sulphur,** by Professor G. Gee, Ph.D., A.R.I.C., F.R.S. Joint Meeting with the University of Nottingham Chemical Society, to be held at the University.

ST. ANDREWS AND DUNDEE.

Thursday, December 8th, 1955, at 5.15 p.m.

Lecture, **Magnetism and the Structure of Inorganic Molecules,** by Professor R. S. Nyholm, M.Sc., A.R.I.C. To be given in the Chemistry Department, Queen's College, Dundee.

SHEFFIELD.

Thursday, December 1st, 1955, at 7.30 p.m.

Lecture, **Directing Effects in Inorganic Substitution Reactions,** by Dr. J. Chatt, M.A., F.R.I.C. Joint Meeting with Sheffield University Chemical Society, to be held in the Department of Chemistry, The University.

SOUTHAMPTON.

Thursday, December 1st, 1955, at 6 p.m.

Lecture, **Principles and Practice of Polymer Design,** by Mr. R. B. Richards, B.A. Joint meeting with the Southern Section of the Plastics Institute and the University of Southampton Chemical Society, to be held in the Chemistry Department, The University.

OFFICIAL ANNOUNCEMENTS

DEATHS

The Council regrets to announce the deaths of the following Fellows:

	Elected.	Died.
Joseph Clifford (Blackpool)	Aug. 7th, 1941.	Apr. 23rd, 1955.
Ronald Leslie Collett (N.W.8)	June 16th, 1910.	Aug. 15th, 1955.
James Codrington Crocker (West Wickham)	Apr. 30th, 1902.	Aug. 17th, 1955.
Sydney Glenn Preston Plant (Oxford)	Feb. 16th, 1920.	Sept. 10th, 1955.
Otto Rosenheim (N.W.11)	May 7th, 1896.	May 7th, 1955.
John Frederick Pratt Scallan (Manila)	May 12th, 1949.	July 19th, 1954.
Harold Augustine Tempany (W.14)	May 3rd, 1906.	July 2nd, 1955.
Harry James Yates (W.1)	June 18th, 1908.	Aug. 28th, 1955.

CORDAY-MORGAN MEDAL AND PRIZE.

The Corday–Morgan Medal and Prize, consisting of a Silver Medal and a monetary Prize of 200 Guineas, is awarded annually to the chemist of either sex and of British Nationality, who, in the judgment of the Council of the Chemical Society, shall have published during the year in question the most meritorious contribution to experimental chemistry, and who shall have not, at the date of publication, have attained the age of thirty-six years. The Council has power to suspend the award in any year in which no suitable candidate presents himself or is brought to the notice of the Council.

Copies of the rules governing the award may be obtained from the General Secretary.

Applications or recommendations in respect of the award for the year 1954 must be received not later than December 31st, 1955, and applications for the award for 1955 are due before the end of 1956.

INTERNATIONAL SYMPOSIUM ON MACROMOLECULAR CHEMISTRY—POLYMERS, BIOCOLLOIDS, POLYELECTROLYTES IN SOLUTION.

An International Symposium on Macromolecular Chemistry is to be held in Israel from April 3rd to 9th, 1956, under the auspices of the Commission on Macromolecules of the International Union of Pure and Applied Chemistry and the Weizmann Institute of Science, Rehovot. The programme includes scientific meetings and social functions to be held at the Weizmann Institute of Science, the Hebrew University of Jerusalem, and the Israel Institute of Technology, Haifa.

Fellows desiring to participate should communicate with the Central Office of the Symposium on Macromolecular Chemistry, The Weizmann Institute of Science, Rehovot, Israel, from which further information can be obtained.

AMERICAN CHEMICAL SOCIETY PUBLICATIONS 1956.

The non-member prices of American Chemical Society publications for 1956 are given in the table overleaf. The domestic subscription rates given in the table apply to subscribers in the United States and Canada only.

Under a reciprocal agreement Fellows of the Chemical Society may enter subscriptions to the Journals published by the American Chemical Society at a discount of 10 per cent. from the non-member rates. This discount does not now apply to *Chemical Abstracts*, which is no longer published as a periodical but is now authorised and priced as a service.

All enquiries should be addressed to The American Chemical Society, 1155, Sixteenth Street, N.W., Washington, 6, D.C., U.S.A.

Title.	Subscription Classification.	Subscription Rates. 1 Year.	2 Years.	3 Years.	Postage Extra, Yearly. Foreign.	Canadian.
Chemical Abstracts Service with Indexes	Teaching Institutes.* (Foreign or Domestic)	$80.00	None	None	$3.00	$1·00
	All Others (Foreign or Domestic)	350.00	,,	,,	None	None
Chemical Abstracts Service without Indexes	Teaching Institutes.* (Foreign or Domestic)	65.00	,,	,,	2.40	0.80
	All Others (Foreign or Domestic)	320.00	,,	,,	None	None
Industrial and Engineering Chemistry	Domestic (all classes of subscribers)	5.00	$8.00	$11.00	—	—
	Foreign (all classes of subscribers)	15.00	27.50	40.00	2.70	0.90
Chemical and Engineering News	Domestic (ditto)	6.00	10.00	14.00		
	Foreign (ditto)	15.00	27.50	40.00	3.00	1.00
Journal of Agricultural and Food Chemistry	Domestic (ditto)	6.00	11.00	15.00		
	Foreign (ditto)	12.00	22.00	30.00	1.50	0.50
Analytical Chemistry	Domestic (ditto)	5.00	9.00	12.00		
	Foreign (ditto)	15.00	27.50	40.00	1.50	0.50
Journal of the American Chemical Society	Domestic (ditto)	30.00	None	None		
	Foreign (ditto)	30.00	,,	,,	3.30	1.10
The Journal of Physical Chemistry	Domestic (ditto)	16.00	,,	,,		
	Foreign (ditto)	16.00	,,	,,	1.20	0.40
The Journal of Organic Chemistry	Domestic (ditto)	25.00	,,	,,		
	Foreign (ditto)	25.00	,,	,,	1.50	0.50

* Teaching institutions, their departments and libraries, take the $80.00 rate ($65.00 without indexes); all other libraries, public or private, take the $350.00 rate ($320.00 without indexes).

All American Chemical Society journals and services are available to its Members at special prices which are available on request. No discount is given on Member subscriptions.

LIST OF APPLICATIONS FOR FELLOWSHIP

(Fellows wishing to lodge objection to the election of these candidates should communicate with the Honorary Secretaries within ten days of the date of publication of the Journal *for October,* 1955. *Such objections will be treated as confidential. The forms of application are available in the Library.)*

Bloom, Stanley Morton, S.B. (M.I.T.) American. Converse Memorial Laboratory, Harvard University, Cambridge, Massachusetts, U.S.A. Graduate Student. *Signed by :* B. S. Christensen, P. Bladon.

Brown, Joseph Patrick, M.Sc. and Ph.D. (Liv.) British. Bryn Castell, Geufron, Llangollen, Denbighshire. Research Chemist with Monsanto Chemicals Ltd., Ruabon. *Signed by :* B. E. Wilde, R. A. Baxter.

Cooper, Alan George, B.Sc. (Lond.) British. 13, Cranley Road, Plaistow, London, E.13. Chemist with The British Drug Houses, Ltd., London, N.1. *Signed by :* E. J. Chappel, H. T. Young.

Davies, Marianne, B.Sc. (Lond.) British. 33, Bradwell Lane, Porthill, Newcastle, Staffs. Research Chemist with Shell Research, Ltd. *Signed by :* D. M. Hall, M. S. Lesslie.

Dunstan, Ivan, B.Sc. and Ph.D. (Bris.) British. 52, Endlebury Road, Chingford, London, E.4. Research Chemist with the Ministry of Supply. *Signed by :* B. Gilbert, J. G. Watkinson.

Goulding, Allan Walter, Irish. 27, Oakley Park, Blackrock, Co. Dublin, Eire. Chief Chemist with Metal Refiners, Ltd., Clondalkin. *Signed by :* M. D. Ranken, V. C. Barry.

Hey, Margaret Eden, B.A. and B.Sc. (Oxon.) British. 70, Durants Road, Enfield, Middlesex. Research Chemist at the National Gallery, London. *Signed by :* W. A. Waters, A. L. J. Beckwith.

Horn, Peter Edwin, B.Sc. and Ph.D. (Leeds). British. 11, Sunnyridge Avenue, Pudsey, Leeds. National Serviceman. *Signed by :* J. W. Baker, E. Rothstein.

Howard, Tom Bellerby, B.Sc. (Exeter). British. 42, Horace Avenue, Rush Green, Romford, Essex. National Serviceman. *Signed by :* S. J. Gregg, K. Schofield.

Largier, John Frank, M.Sc. (Cape Town). South African. Kinkleway, Colenso Road, Claremont, Cape Town, South Africa. Student at the University of Cape Town. *Signed by :* F. G. Holliman, A. M. Stephen.

McGovern, John Gerard, B.Sc. (Glas.) British. 57, Glenburn Avenue, Cambuslang, Glasgow. National Serviceman. *Signed by :* S. H. Tucker, J. B. Thompson.

Marsden, David George Hovell, M.A., B.Sc., D.Phil. (Oxon.) British. Division of Pure Chemistry, National Research Council, Ottawa, Canada. Post-doctoral Fellow. *Signed by :* J. R. Dunn, D. W. Clayton.

May, Peter John, B.Sc. (Lond.) British. Chemistry Department, The University, Glasgow, W.2. Post-graduate research. *Signed by :* D. H. R. Barton, J. C. Orr.

Phillips, Philip Maurice, B.Pharm. (Lond.) British. 4, Talbot Court, Blackbird Hill, Kingsbury, London, N.W.9. Research Student. *Signed by :* A. H. Beckett, M. Donbrow.

Thamm, Richard C., B.S. (State Coll. of Washington). American. Room 260A, Noyes Laboratory, University of Illinois, Urbana, Illinois, U.S.A. Graduate Student. *Signed by :* D. Y. Curtin, F. W. Wassmundt, H. E. Knipmeyer.

Webster, Monica Sylvia (Mrs.), B.A. (Oxon). British. 31, Park Town, Oxford. Research Student. *Signed by :* L. A. K. Staveley, D. M. Hodgkin.

Williams, John Herbert. British. 234, Botwell Lane, Hayes, Middlesex. Chemist. *Signed by :* I. R. H. Crail, B. W. V. Hawes.

Wingfield, Philip Douglas, B.Sc. (Lond.) British. 67, Chelsea Manor Flats, Chelsea, London, S.W.3. Research Student at Queen Mary College, London. *Signed by :* R. F. Hudson, R. Pettit.

Woodwark, William, B.Sc. (Leeds). British. British Sugar Corporation, Ltd., Central Laboratory, Oundle Road, Peterborough, Northants. Research Chemist. *Signed by :* D. Hibbert, E. Rothstein.

UNDER SPECIAL PROVISION APPERTAINING TO CANDIDATES RESIDENT ABROAD.

Bieber, Theodore Immanuel, B.A., M.S., and Ph.D. (New York). Swiss. 80—40, Lefferts Boulevard, Kew Gardens 15, New York, U.S.A. Assistant Professor at Adelphi College, New York. *Signed by :* K. Mislow.

Kao, Wilson Samuel, F.R.P.S., F.R.S.A. Chinese. 366, River Valley Road, Singapore 9, (P.O. Box 106), Malaya. Research and Development Chemist. *Signed by :* R. L. Huang.

PAPERS ACCEPTED

(List of Papers accepted between August 27th, 1955, and September 27th, 1955, for publication in the *Journal*.)

" The chemotherapy of tuberculosis. Part V. Thiosemicarbazones of substituted phenyl- and pyridyl-benzaldehydes." By J. Cymerman-Craig and J. W. Loder.

" Solutions of alcohols in non-polar solvents. Part III. The viscosities of dilute solutions of primary alcohols in benzene, heptane, and *cyclo*hexane." By L. A. K. Staveley and P. F. Taylor.

" Cinnolines and other heterocyclic types in relation to the chemotherapy of trypanosomiasis. Part XI. Some reactions of simple quinoxaline derivatives." By C. M. Atkinson, C. W. Brown, and (the late) J. C. E. Simpson.

" Chemistry of nitrosyl complexes. Part II. Exchange of ^{36}Cl between nitrosyl chloride and some insoluble metal chlorides." By J. Lewis and D. B. Sowerby.

" The effect of solvents on the molecular complexities of tantalum *n*-alkoxides." By D. C. Bradley, W. Wardlaw, and (Miss) Alice Whitley.

" The addition of thiolacetic acid to ethynylcarbinols and the conversion of the adducts into aldols and αβ-unsaturated aldehydes." By Henry Bader.

" The enzymic synthesis and degradation of starch. Part XX. The disproportionating enzyme (D-enzyme) of the potato." By Stanley Peat, W. J. Whelan, and W. R. Rees.

" Synthesis of the mononitrophenanthrenes." By P. M. G. Bavin and M. J. S. Dewar.

" The Rapson triphenylene synthesis and its application to 1 : 2·3 : 4-dibenzophenanthrene." By P. M. G. Bavin and M. J. S. Dewar.

" Crystalline 2 : 3-di-*O*-methyl-β-D-xylose." By Eric G. Meek.

" The kinetics of the alkaline hydrolysis of esters and amides of 1- and 2-naphthoic acids." By P. Fitzgerald, J. Packer, J. Vaughan, and A. F. Wilson.

" Stereochemical studies of olefinic compounds. Part V. Further observations on the ring scission of 3-chlorotetrahydro-furans and -pyrans." By L. Crombie, (Mrs.) J. Gold, S. H. Harper, and B. J. Stokes.

" 2-Bromo-4- and -5-methylbenzoic acid and some related compounds." By M. S. GIBSON.
" The reaction of magnesium halides with αβ-anhydro-sugars." By G. N. RICHARDS, L. F. WIGGINS, and W. S. WISE.
" Reactions in the diene series : condensation of isoprene with aniline and phenol." By G. R. CLEMO and N. D. CHATGE.
" Degradative studies on peptides and proteins. Part II. Synthesis and properties of 3-benzoyl-1-phenyl-2-thiohydantoin." By D. T. ELMORE and P. A. TOSELAND.
" Degradative studies on peptides and proteins. Part III. Synthesis of some 2-thiohydantoins as reference compounds." By D. T. ELMORE, J. R. OGLE, and P. A. TOSELAND.
" Magnetochemistry of the heaviest elements. Part IX. The system : UO_2–ThO_2–O." By J. K. DAWSON and L. E. J. ROBERTS.
" Compounds of potential pharmacological interest. Part V. 2-Substituted 1-phenylindanes." By J. A. BARLTROP and R. F. DODSWORTH.
" A search for new trypanocides. Part I. Preparation of 2 : 7-diamino- and 2 : 7-di-(ethoxycarbonylamino)-10-methylphenanthridinium salts. Preparation of 2 : 7-diamino-9-anilino- and -9-*p*-aminoanilino-phenanthridine and attempted conversion of them into quaternary salts." By M. DAVIS.
" Terpenes. Part IX. A method of formation of homo*apo*camphoric acid." By R. N. ADHYA, A. C. GHOSH, and J. C. BARDHAN.
" Galloflavin. Part III. The position of the carboxyl group in *iso*galloflavin and a synthesis of trimethylbrevifolin." By JAMES GRIMSHAW and ROBERT D. HAWORTH.
" Addition reactions of heterocyclic compounds. Part II. Phenanthridine and methyl acetylenedicarboxylate in methanol." By R. M. ACHESON and G. J. F. BOND.
" The action of sodium iodide on methyl 4 : 6-*O*-benzylidene-3-deoxy-3-iodo-2-*O*-toluene-*p*-sulphonyl-α-D-glucoside." By F. H. NEWTH.
" Enol isomerism in the tropine series." By C. A. FRIEDMANN and J. M. Z. GLADYCH.
" The enzymic synthesis and degradation of starch. Part XXI. The dextrins synthesised by D-enzyme." By STANLEY PEAT, W. J. WHELAN, and (the late) G. W. F. KROLL.
" Isotopic studies on the formation of ketones by the catalytic decomposition of certain acids." By ROWLAND I. REED.
" Triterpenoids. Part XLVII. The constitution of some compounds obtained by the dehydration of β-amyrin and related alcohols. Further observations on the stereochemistry of α-amyrin." By G. G. ALLAN, M. B. E. FAYEZ, F. S. SPRING, and ROBERT STEVENSON.
" The pyrolysis of organomercury compounds." By H. V. CARTER, E. I. CHAPPELL, and E. WARHURST.
" Addition of free radicals to unsaturated systems. Part XII. Free-radical and electrophilic attack on fluoro-olefins." By R. N. HASZELDINE and J. E. OSBORNE.
" The decomposition of hydrogen peroxide by ceric salts. Part II. The action of ceric perchlorate." By MICHAEL ARDON and GABRIEL STEIN.
" The diffusion coefficient of hydrogen in iron." By T. M. STROSS and F. C. TOMPKINS.
" Complexes of nickel and cobalt with certain chelate compounds." By S. E. LIVINGSTONE.
" Complexes of palladium and platinum with certain chelate compounds." By S. E. LIVINGSTONE.
" The infrared spectra of liquid and solid formic acid." By D. CHAPMAN.
" The reaction of *o*-di-iodobenzene with magnesium, lithium, and *n*-butyl-lithium." By H. HEANEY, F. G. MANN, and I. T. MILLAR.
" *o*-Mercapto-azo-compounds. Part VIII. Preparation and debenzylation of 2-benzylthio-2′- and -4′-nitroazobenzene." By A. BURAWOY, A. CHAUDHURI, and C. E. VELLINS.
" *o*-Mercapto-azo-compounds. Part IX. Debenzylation of 1-benzylthio-2-phenylazonaphthalene." By A. BURAWOY, A. CHAUDHURI, and W. I. HYSLOP.

" 3- and 5-Ethyloctahydropyrrocolines." By K. S. N. PRASAD and R. RAPER.
" Further comments on the absorption spectra and stability of complex ions." By R. J. P. WILLIAMS.
" Improvements in the preparation of [9-^{14}C]fluorene and [9-^{14}C]phenanthrene." By A. S. HARRIS, E. N. WHITE, and D. MCNEIL.
" Calculated bond lengths in some cyclic compounds. Part III. Benzoic acid." By T. H. GOODWIN.
" The analysis of inorganic compounds by paper chromatography. Part VIII. The separation of the thionic acids by a new paper chromatographic technique." By F. H. POLLARD, J. F. W. MCOMIE, and D. J. JONES.
" Studies in the chemistry of quadrivalent germanium. Part III. Ion-exchange studies of solutions containing germanium and oxalate." By D. A. EVEREST.
" Experiments on the synthesis of the pyrethrins. Part X. Intermediates for the synthesis of *cis*-pyrethrolone." By L. CROMBIE, S. H. HARPER, F. C. NEWMAN, D. THOMPSON, and (in part) R. J. D. SMITH.
" Studies in hydrogen-bond formation. Part V. The reactivity of amines, amides, and azo-compounds in aqueous and non-aqueous solutions." By F. M. ARSHID, C. H. GILES, S. K. JAIN, and A. S. A. HASSAN.
" Thermochromism of compounds containing the thiocarbonyl and disulphide functions." By J. C. D. BRAND and J. R. DAVIDSON.
" The solvolysis of 1-chloropropan-2-ol." By I. K. GREGOR, N. V. RIGGS, and V. R. STIMSON.
" The reaction between quinones and anthranilic acids." By R. M. ACHESON and B. F. SANSOM.
" Fungicidal activity and chemical constitution. Part IV. Synthesis of 5-*n*-alkyl-8-hydroxyquinolines." By D. WOODCOCK, (MISS) V. W. ROGERS, and (MRS.) P. M. POPE.
" 3 : 5-Dichloropentan-2-one." By L. CROMBIE, S. H. HARPER, and B. J. STOKES.
" Catalytic reduction of acetobromo-sugars." By L. ZERVAS and (MISS) C. ZIOUDROU.
" *Rauwolfia* alkaloids. Part I. Reserpine and ajmaline from *R. natalensis* Sond. (*R. caffra*)." By BRUNO O. G. SCHULER and F. L. WARREN.
" Some reactions of *o*-nitrobenzenesulphenyl bromide." By A. BURAWOY, P. RAYMAKERS, and C. TURNER.
" Sesquiterpenoids. Part VII. The constitution of tenulin, a novel sesquiterpenoid lactone." By D. H. R. BARTON and P. DE MAYO.
" Polynuclear heterocyclic systems. Part IX. n–π^*-Transitions in the spectra of aromatic aza-compounds." By G. M. BADGER and I. S. WALKER.
" The preparation of some glucose nitrates." By D. O'MEARA and D. M. SHEPHERD.
" Terpene compounds. Part VIII. The conversion of (±)-benzylidenepiperitone into 3-*iso*propylphenanthrene." By J. C. BARDHAN and R. N. ADHYA.
" Mannose-containing polysaccharides. Part IV. The glucomannans of lily bulbs." By P. ANDREWS, L. HOUGH, and J. K. N. JONES.
" The electronic spectrum of formaldehyde." By J. C. D. BRAND.

ADDITIONS TO THE LIBRARY

Items marked with an asterisk (*) are for reference only. Otherwise the following books will be available for loan after October 26th, 1955.

*AMERICAN CHEMICAL SOCIETY. Physical properties of chemical compounds. American Chemical Society. 1955. 52*s*.

AMERICAN PUBLIC HEALTH ASSOCIATION. Standard methods for the examination of water, sewage, and industrial wastes, 10th ed. American Public Health Association. 1955. 60*s*.

BARLOW, R. B. Introduction to chemical pharmacology. Methuen. 1955.
(Presented by Publisher.)

BRAUDE, E. A., and NACHOD, F. C. (Eds.). Determination of organic structures by physical methods. Academic Press. 1955. 107*s*.

FREAR, D. E. H. Chemistry of the pesticides, 3rd ed. Van Nostrand. 1955. 60*s*.

GARNER, W. E. (Ed.). Chemistry of the solid state. Butterworths. 1955. 50*s*.

GARRATT, D. C. The quantitative analysis of drugs, 2nd ed. Chapman and Hall, Ltd. 1955. (Presented by Publisher.)

GEIGY, J. R., S.A., Basle (Switzerland). Traugott Sandmeyer. J. R. Geigy, S.A. 1955. (Presented by Publisher.)

HARRY, R. G. The principles and practice of modern cosmetics. Vol. 1. Modern cosmeticology, 4th ed. Leonard Hill. 1955. 65*s*.

HARVEY, H. W. The chemistry and fertility of sea waters. Cambridge University Press. 1955. 30*s*.

*HATT, H. H., PEARCEY, T., SZUMER, A. Z. Anti-composition tables for carbon compounds. Cambridge University Press. 1955. 21*s*.

KORTÜM, G. Kolorimetrie, Photometrie und Spektrometrie, 3rd ed. Springer. 1955. 63*s*.

LEDERER, M. An introduction to paper electrophoresis and related methods. Elsevier. 1955. 37*s*. 6*d*.

LUBS, H. A. The chemistry of synthetic dyes and pigments. Reinhold. 1955. £7 8*s*.

MCBAIN, M. E. L., and HUTCHINSON, E. Solubilization and related phenomena. Academic Press. 1955. 56*s*.

MCDONALD, H. J. (*et al.*). Ionography. Year Book Publishers. 1955. 48*s*.

PALIT, S. R., DAS, M. N., SOMAYAJULU, G. R. Non-aqueous titration. Indian Association for the Cultivation of Science. 1954.
(Presented by Author.)

PENNER, S. S. Introduction to the study of chemical reactions in flow systems. Butterworths. 1955. 21*s*.

*ROSIN, J. Reagent chemicals and standards. Van Nostrand. 1955. 70*s*.

SMYTH, C. P. Dielectric behavior and structure. McGraw-Hill. 1955.
(Presented by Publisher.)

SULLY, A. H. Manganese. Butterworths. 1955. 40*s*.

TOIVONEN, N. J. (Ed.). Biochemistry of nitrogen. A collection of papers on biochemistry of nitrogen and related subjects dedicated to Artturi Ilmari Virtanen on the occasion of his 60th birthday, January 15th, 1955. Suomalainen Tiedeakatamia. 1955. 90*s*.

TROTMAN-DICKENSON, A. F. Gas kinetics. Butterworths. 1955. 40*s*.

VEIBEL, S. The identification of organic compounds, 4th ed. G. E. C. Gad. 1954. 46*s*. 6*d*.

PROCEEDINGS

OF THE

CHEMICAL SOCIETY

SCIENTIFIC MEETINGS DURING JANUARY, 1956

LONDON.

Thursday, January 19th, 1956, at 7.30 p.m.

Tilden Lecture, **Recent Progress in the Chemistry of Peptides,** by Dr. G. W. Kenner, M.Sc. To be given in the Large Chemistry Lecture Theatre, Imperial College of Science and Technology, South Kensington, S.W.7.

ABERDEEN.

Friday, January 13th, 1956, at 7.30 p.m.

Lecture, **Some Naturally Occurring Polyacetylenes,** by Professor B. Lythgoe, M.A., Ph.D. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry, to be held at Marischal College.

BIRMINGHAM.

Friday, January 27th, 1956, at 4.30 p.m.

Lecture, **Some Chemical Aspects of Plant Growth Regulation,** by Professor R. L. Wain, D.Sc., Ph.D., F.R.I.C. Joint Meeting with Birmingham University Chemical Society to be held in the Chemistry Department, The University.

BRISTOL.

Thursday, January 19th, 1956, at 7 p.m.

Lecture, **Trapped Radicals in Polymerisation Reactions,** by Dr. C. H. Bamford, M.A., A.R.I.C. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry, to be held in the Department of Chemistry, The University.

Thursday, January 26th, 1956, at 7 p.m.

Lecture, **Industrial Applications of Sequestering Agents,** by Messrs. R. L. Smith and P. Womersley. Joint Meeting with the Royal Institute of Chemistry, the Society of Chemical Industry, and the Society for Analytical Chemistry, to be held in the Department of Chemistry, The University.

CAMBRIDGE.

Friday, January 20th, 1956, at 8.30 p.m.

Lecture, **A Topic in Natural Product Chemistry,** by Professor D. H. R. Barton, D.Sc., F.R.I.C., F.R.S. Joint Meeting with the University Chemical Society to be held in the University Chemical Laboratory, Pembroke Street.

EDINBURGH.

Thursday, January 12*th*, 1956, *at* 7.30 *p.m.*

Lecture, **Worm Infestation. The Chemist's Approach to an Important National Problem,** by Dr. A. Mackie, D.Sc., F.R.S.E. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry, to be held at the North British Station Hotel.

LEEDS.

Monday, January 16*th*, 1956, *at* 6.30 *p.m.*

Royal Institute of Chemistry Lecture, **Some Observations of the Production of Antibiotics,** by Mr. W. B. Emery, B.Sc., F.R.I.C. To be given in the Chemistry Lecture Theatre, The University. (All Fellows invited.)

LIVERPOOL.

Thursday, January 19th, 1956, *at* 5 *p.m.*

Lecture, **Chemical Aspects of Nucleotide Biosynthesis,** by Professor J. Baddiley, M.Sc., Ph.D. Joint Meeting with the Royal Institute of Chemistry, the Society of Chemical Industry, the British Association of Chemists, and the University Chemical Society, to be held in the Chemistry Lecture Theatre, The University.

MANCHESTER.

Thursday, January 19*th*, 1956, *at* 6.30 *p.m.*

Lecture, **Aromatic Substitution,** by Professor M. J. S. Dewar, M.A., D.Phil. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry, to be held in Room E. 17, College of Technology, Manchester.

NEWCASTLE AND DURHAM.

Friday, January 27*th*, 1956, *at* 5.30 *p.m.*

Bedson Club Lecture, **The Chemistry of Inontin,** by Dr. F Sanger. To be given in the Chemistry Building, King's College, Newcastle-on-Tyne, 1. (All Fellows are invited.)

NORTHERN IRELAND.

Tuesday, January 24th, 1956, *at* 7.15 *p.m.*

Lecture, **Some Applications of Science in the Detection of Crime,** by Dr. J. B. Firth, C.B.E., F.R.I.C. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry, to be held at The Queen's University, Belfast.

NOTTINGHAM.

Monday, January 30*th*, 1956, *at* 4.45 *p.m.*

Lecture by Professor C. A. Coulson, Ph.D., D.Sc., F.R.S. Joint Meeting with the University of Nottingham Chemical Society to be held at The University.

SOUTHAMPTON.

Thursday, January, 12th, 1956, at 7 p.m.

Lecture, **Qualitative Analysis—New Techniques and Old Problems,** by Mr. H. Holness, M.Sc., F.R.I.C. Joint Meeting with Portsmouth and District Chemical Society to be held at the College of Technology, Anglesea Road, Portsmouth.

Friday, January 27th, 1956, at 5.0 p.m.

Lecture, **Recent Advances in the Chemistry of the Adrenal Cortex,** by Professor C. W. Shoppee, D.Sc., A.R.C.S., F.R.I.C. Joint Meeting with Southampton University Chemical Society to be held in the Chemistry Department, The University, Southampton.

SOUTH WALES.

The Lecture **Actinide Elements,** by Mr. H. A. C. McKay, B.A., arranged for January 27th, 1956, has been postponed and will be given on February 3rd, 1956, at 6 p.m.

OFFICIAL ANNOUNCEMENTS

DEATHS

The Council regrets to announce the deaths of the following Fellows :

	Elected.	Died.
Salah Eldin Said El Wakkad (Giza)	Oct. 2nd, 1947.	Sept. 21st, 1955.
Lionel Felix Gilbert (Beaconsfield)	Dec. 4th, 1919.	Oct. 3rd, 1955.
Charles Edward Sage (London, N.2)	Feb. 20th, 1896.	Sept. 4th, 1955.

ELECTION OF NEW FELLOWS.

The following 13 candidates were elected Fellows of the Society on October 20th, 1955 :

Agnes McMillen Anderson.
Bryant Charles Fischback.
David John Goodall.
Alastair Campbell Gowan.
William Duane Huntsman.
Robert Kelly Ingham.
Robert McCrone Laird.
Ralph John Martin.
Adam Mieczyslaw Alexander Mincer.
Sripada Kameswara Pavanaram.
Theodora Stephen.
Maurice Vernon Walshaw.
Peter Yates.

MEMBERS OF COUNCIL.

Dr. A. W. Johnson has resigned as a member of Council for Constituency I on his appointment as Professor of Chemistry at Nottingham University, and the Council has appointed Dr. G. W. Kenner to fill the vacancy until the Annual General Meeting in 1956.

LOCAL REPRESENTATIVES.

Professor A. J. Birch, who is soon to leave Australia, has resigned as Local Representative. The President has conveyed the thanks of the Society to Professor Birch for his services, and the appointment of a successor is under consideration.

PROFESSOR M. CALVIN—CENTENARY LECTURER.

Professor M. Calvin has just completed a lecture tour of Britain and has given the Centenary Lecture entitled " The Photosynthetic Carbon Cycle " at a number of centres.

He gave the lecture in London, where he was presented with the Flintoff Medal, on October 20th, in Birmingham on October 24th, at an Official Meeting in Glasgow on October 28th, and in Manchester on November 1st. He also gave the 100th Bedson Club Lecture at Newcastle-on-Tyne on October 26th.

LIBRARY.

The Library will be closed for the Christmas Holidays from 1 p.m., Friday, December 23rd, until 10 a.m., Thursday, December 29th, 1955.

MINUTES OF SCIENTIFIC MEETINGS

Minutes of a

SCIENTIFIC MEETING

held at the Institution of Civil Engineers, on Thursday, October 20th, at 7.30 p.m.

The President, Professor W. Wardlaw, D.Sc., F.R.I.C., was in the Chair.

MINUTES.

The Minutes of the Scientific Meetings held at Burlington House on June 2nd, at the Physical Chemistry Laboratory, South Parks Road, Oxford, on June 6th, and at the University College of the South-west of England, Exeter, on July 13th, 14th and 15th, 1955, were read, and were confirmed and signed.

FORMAL ADMISSION OF FELLOWS.

The following were admitted Fellows of the Society : Melvin Calvin, Stanley J. Cristol, B. A. Knights, J. Lett, G. W. Loveday, J. R. Quayle, R. D. Guthrie, M. A. Sparks, J. Phillips, N. A. J. Rogers, Alan E. Comyns, K. W. Everest, M. Romero, F. H. Herbstein, E. Irene Beeching, Edward W. Abel, David Samuel.

FLINTOFF MEDAL AND PRIZE.

The President presented the Flintoff Medal and Prize for 1953 to Professor M. Calvin.

CENTENARY LECTURE.

The President called upon Professor M. Calvin to deliver the Centenary Lecture entitled " The Photosynthetic Carbon Cycle."

At the conclusion of the Lecture, a vote of thanks to Professor Calvin, proposed by Professor T. A. Bennett-Clark, F.R.S., and was carried with acclamation.

Minutes of a

SCIENTIFIC MEETING

held in the Chemistry Department, The University, Glasgow, on Friday, October 28th, 1955, at 4 p.m.

The President, Professor W. Wardlaw, C.B.E., D.Sc., F.R.I.C., was in the Chair.

FORMAL ADMISSION OF FELLOWS.

The following were admitted Fellows of the Society : John S. Davidson, W. Crawford Paterson, Ian D. R. Stevens, Clare B. Wylam, Donald J. Mackenzie, Jean M. Tyler, Theodore Cohen, John R. Crowder, James B. Thomson, James G. Sime, C. H. Giles, Andrew L. Porte, Ian G. Wallace, Hamilton Smith, R. D. Smith, J. Silverton, M. N. Rodger, Colin Taylor Ironside, William Templeton, George A. Morrison, Juliann M. Calder, William W. Kerr, Margaret A. M. Cameron, Ian C. McNeill, L. E. Sutton.

CENTENARY LECTURE.

The President called upon Professor Melvin Calvin, Ph.D., to deliver the Centenary Lecture entitled " The Photosynthetic Carbon Cycle." At the conclusion of the Lecture a vote of thanks to Professor Calvin, proposed by Professor E. L. Hirst, F.R.S., was carried with acclamation.

Professor D. H. R. Barton, F.R.S., on behalf of local Fellows, thanked the Society for holding an official meeting in Glasgow, and the President replied.

LIST OF APPLICATIONS FOR FELLOWSHIP

(Fellows wishing to lodge objection to the election of these candidates should communicate with the Honorary Secretaries within ten days of the date of publication of the Journal *for November, 1955. Such objections will be treated as confidential. The forms of application are available in the Library.)*

Andrews, John Napier, B.Sc. and Ph.D. (Q.U.B.). British. Imperial College of Science and Technology, Department of Chemical Engineering and Applied Science, Prince Consort Road, South Kensington, S.W.7. Research Student. *Signed by :* A. R. Ubbelohde, D. M. Newitt.

Arnett, Edward McCollin, A.B., M.S., and Ph.D. (Penna.). American. 74-A, Garfield Street, Cambridge, 38, Mass., U.S.A. Research Fellow at Harvard University. *Signed by :* H. Hart, J. J. Brown, J. C. Martin.

Ashton, Bryan Webb, B.Sc. (Lond.). British. 7, Moss Lane, Swinton, Nr. Manchester. Research Student. *Signed by :* H. Suschitzky, G. R. Ramage.

Balsillie, Andrew. British. 72, Seres Road, Clarkston, Glasgow. Student at Glasgow University. *Signed by :* J. Bell, D. S. Payne.

Banthorpe, Derek Victor, B.Sc. (Lond.). British. 162, Henniker Gardens, East Ham, London, E.6. Research Student at University College, London. *Signed by :* C. K. Ingold, E. D. Hughes.

Batten, Jeffrey John, B.Sc. (Melbourne). British. 8, Kerferd Road, Albert Park, S.C.6, Melbourne, Australia. Research Chemist at C.S.I.R.O. *Signed by :* M. F. R. Mulcahy, K. H. Pausacker.

Blundy, Peter Desmond, B.Sc. (Lond.). British. Icknield Way House, A.E.R.E., Harwell, Didcot, Berks. Asst. Experimental Officer. *Signed by :* F. Schofield, J. D. Bower.

Branch, Sidney John, B.Sc. and Ph.D. (Lond.). British. 12, Quendon Drive, Waltham Abbey, Essex. Research Chemist. *Signed by :* G. W. Gray, K. Rothwell.

Bray, Leonard George, B.Sc. (Lond.). British. 39, High Street, Northwood, Middlesex. Research Student. *Signed by :* J. F. J. Dippy, S. R. C. Hughes.

Buchwald, Herbert, B.Sc. (Lond.). Stateless. 76, Leicester Road, Salford, 7, Lancs. Research Student at the Royal Technical College, Salford. *Signed by :* W. P. Thistlethwaite, P. J. Coope.

Burt, James Robertson, B.Sc. (St. Andrews). British. Boarhills Farm House, Boarhills, St. Andrews, Fife. Research Student. *Signed by :* S. Bayne, C. Horrex.

Burton, Henry Stowar, M.Sc. (Lond.), D.Phil. (Oxon), A.R.C.S. British. 41, Blandford Avenue, Oxford. Research Fellow at Oxford University. *Signed by :* J. C. Smith, L. J. Goldsworthy.

Bushman, David Trevor. British. 47, Glenalmond Road, Sheffield, 11. Student. *Signed by :* P. A. H. Wyatt, H. J. V. Tyrrell.

Charman, Hugh Bernard, B.Sc. (Lond.). British. 2, Bryanstone Road, Bournemouth. Research Student. *Signed by :* E. D. Hughes, C. K. Ingold.

Curry, Peter Edward, B.A. (Oxon.). British. 40, Gubbins Lane, Harold Wood, Romford, Essex. Student at Keble College, Oxford. *Signed by :* L. A. K. Staveley, L. A. Woodward.

Dart, Michael Charles, B.Sc. (Manc.). British. Carfax, Lower Park Road, Victoria Park, Manchester, 14. Research Student. *Signed by :* G. R. Barker, W. B. Turner.

Dawber, John Graham. British. 42, Elmfield Avenue, Sheffield, 5, Yorks. Student at Sheffield University. *Signed by :* H. J. V. Tyrrell, A. S. C. Lawrence.

Fazi, Gabriel Paschal. British. 96, Camberwell Grove, London, S.E.5. Student. *Signed by :* J. F. McGhie, J. F. J. Dippy.

Gobran, Ramsis, B.Sc. (Alexandria). Egyptian. Chemistry Department, University of Southern California, Los Angeles 7, California. Laboratory Associate. *Signed by :* M. C. Kloetzel, J. A. Berson.

Grdenic, Drago, Ph.D. (Zagreb). Yugoslav. Laboratory for General and Inorganic Chemistry, Faculty of Science, Strosmajerov trg 14, Zagreb, Yugoslavia. Research at Faculty of Science, Zagreb. *Signed by :* D. M. Hodgkin, H. M. Powell.

Hardy, Francis Robert Frederick, B.Sc. (Lond.). British. 313, Cressing Road, Braintree, Essex. Post-graduate Student at The Royal College of Science. *Signed by :* D. W. Turner, E. A. Braude.

Harrison, Derek, B.Sc. (Leeds). British. 6, Princess Street, Whitworth, Rochdale, Lancs. Research Student at Leeds University. *Signed by :* J. R. Holker, J. B. Speakman.

Harrison, Ian Thomas, B.Sc. (Leeds). British. 29, Ash Grove, Hyde Park, Leeds, 6. Research in Organic Chemistry. *Signed by :* J. N. Baxter, E. Rothstein.

Harrold, Jeremy Robin, B.A. (Oxon.). British. Radley College, Nr. Abingdon, Berks. Schoolmaster. *Signed by :* L. A. K. Staveley, F. M. Brewer.

Hazell, John Evan, B.A. (Queen's). Canadian. 382, Earl Street, Kingston, Ontario, Canada. Student. *Signed by :* H. G. McAdie, K. E. Russell.

Hichens, Robert Enys, B.A. (Oxon.). British. The Lensbury Club, Broom Road, Teddington, Middlesex. Chemical Industry Administration, Shell Petroleum Co. *Signed by :* L. A. K. Staveley, L. E. Sutton.

Kaesz, Herbert David, A.B. (New York). American. Mallinckrodt Chemistry Laboratories, Harvard University, 12, Oxford Street, Cambridge 38, Massachusetts, U.S.A. Graduate Student-Teaching Fellow. *Signed by :* W. A. G. Graham, F. G. A. Stone.

Kennedy, Michael. British. 7, Marsden Place, Beeston, Leeds, 11. Student at Sheffield University. *Signed by :* P. A. H. Wyatt, P. L. Pauson.

Kirby, Gordon William, B.A. (Cantab.). British. 19, Brierfield Road, Liverpool, 15. Research Student. *Signed by :* A. H. Neilson, W. G. Hanger.

Letters, Robert, B.Sc. (Dunelm). British. 18, Jesmond Vale Terrace, Heaton Road, Newcastle-on-Tyne, 6. Research Student at King's College, Newcastle. *Signed by :* J. Baddiley, R. Raper.

Little, John Stanley, B.Sc. and Ph.D. (New Brunswick). Canadian. London House, Guilford Street, London, W.C.1. Post-Doctorate Student at Imperial College. *Signed by :* M. Romero, G. Lowe.

Macleod, Kenneth James, B.Sc. (Queen's). Canadian. 202, Helen Street, Kingston, Ontario, Canada. Student. *Signed by :* J. K. N. Jones, T. J. Painter.

Newbould, John. British. The Croft, Linton, Wetherby, Yorks. Undergraduate at Oriel College, Oxford. *Signed by :* L. A. K. Staveley, B. R. Brown.

Newton-Hearn, Primula Anne, B.Sc. (Birm.). British. 5, Blackwood Road, Streetly, Staffs. Research Student. *Signed by :* D. Horton, R. P. Smith.

Nicholls, David. British. 26, Eva Road, Gillingham, Kent. Student. *Signed by :* N. B. Chapman, G. W. A. Fowles.

Norton, Peter. British. 17, Woodstock Road, Balby, Doncaster. Student at Sheffield University. *Signed by :* J. Lewis, H. J. V. Tyrrell.

Phillips, Sidney Bertram, F.R.I.C. British. 7, Norman Road, Northfield, Birmingham, 31. Chief Chemist at Cadbury Brothers Ltd. *Signed by :* R. V. Wadsworth, W. B. Walker.

Pilcher, Geoffrey, M.A. and D.Phil (Oxon.). British. 4916, Forbes Street, Pittsburgh 13, Pennsylvania, U.S.A. Reserch Chemist at the Carnegie Institute of Technology. *Signed by :* L. A. K. Staveley, L. E. Sutton.

Ransome, Norman Edward, B.A. (Oxon.). British. 25, Springdale Road, Broadstone. Dorset. Research Student. *Signed by :* L. A. K. Staveley, J. A. Barltrop.

Robinson, Edward Arthur, B.Sc. (Lond.). British. 193, Devonshire Road, Forest Hill, London, S.E.23. Research Student at University College, London. *Signed by :* R. J. Gillespie, E. D. Hughes.

Rozanski, Andrzej, B.Sc. (Lond.). Polish. 8, Coleherne Road, London, S.W.10. Research Student at Chelsea Polytechnic. *Signed by :* J. F. J. Dippy, S. R. C. Hughes.

Schofield, John Antony, B.Sc.Tech. and Ph.D. (Manc.), A.R.I.C. British. 291, Ashton Road East, Failsworth, Manchester. Assistant Lecturer. *Signed by :* H. N. Rydon, S. Hollingshead.

Shrivastav, Promode Prakash, M.Sc. (Rajputana). Indian. Jaswant College, Jodhpur, India. Lecturer. *Signed by :* T. R. Seshadri, G. S. Saharia.

Simamura, Osamu, D.Sc. (Tokyo). Japanese. 615, 2-Chome, Omiyamae, Suginamiku, Tokyo, Japan. Professor at Tokyo University. *Signed by :* S. Shibata, S. Sugasawa.

Skuse, Frank. British. 10, Webster Street, Platt Bridge, Wigan, Lancs. Student at Sheffield University. *Signed by :* J. Lewis, H. J. V. Tyrrell.

Smith, Brian Robson, B.Sc. (Manc.). British. 69, Hillside Avenue, Clarkesfield, Oldham, Lancs. Student. *Signed by :* G. R. Barker, G. C. Sayer.

Speakman, Peter Trafford, M.A. and Ph.D. (Oxon.). British. 181, Otley Road, Leeds, 6. International Wool Secretariat Fellow at Leeds University. *Signed by :* E. V. Truter, F. P. Woodward.

Tanaka, Sanae, D.Sc. (Tokyo). Japanese. Department of Chemistry, Tokyo University of Education, 24, Otsuka-Kubomachi, Bunkyo-ku, Tokyo, Japan. Lecturer. *Signed by:* H. Suginome, S. Sugasawa.

Taylor, Brian Leslie. British. 36(b), Alexandra Road, Windsor, Berks. Student at Queen Mary College, London. *Signed by:* W. J. Hickinbottom, R. F. Garwood.

Thompson, Malcolm James. Australian. 9, Rodney Street, Woodville, South Australia. Student. *Signed by :* J. W. Clark-Lewis, P. R. Jefferies.

Tillett, John Graham, B.Sc. (Lond.). British. 15, The Mall, Southgate, London, N.14. Research Student. *Signed by :* P. B. D. De La Mare, C. A. Bunton.

Todd, John Francis James. British. 20, Montague Crescent, Leeds, 8. Student. *Signed by :* E. Rothstein, N. H. Hartshorne.

Trethewey, Peter Douglas. British. 1, Alverton Street, Penzance, Cornwell. Student at King's College, London. *Signed by :* J. Honeyman, K. Mackenzie.

Turner, Kenneth Holmes. British. 37, Lancaster Avenue, Kirk Sandall, Nr. Doncaster, Yorks. Analyst at Rockware Glass Ltd. *Signed by :* D. Mullin, W. Sowden.

Watson, Douglas Hugh, B.Sc. and Ph.D. (Glas.). British. Kelvin Lodge, Park Circus, Glasgow, C.3. Assistant Lecturer at Glasgow University. *Signed by :* J. M. Robertson, I. M. Dawson.

Wheatley, Peter Jaffrey, M.A. and D.Phil. (Oxon.). British. School of Chemistry, The University, Leeds, 2. Lecturer. *Signed by :* E. Rothstein, J. H. Robertson.

Wich, Grosvenor Searles, M.S. and Ph.D. (Carnegie Inst. of Technology). American. 45B, Elsmere Boulevard, Silverbrook Gardens, Wilmington 5, Deleware, U.S.A. Research Chemist. *Signed by :* S. W. Caywood, L. F. Donaruma.

Williams, John Colin. British. 203, Albany Street, London, N.W.1. Chemical Merchant. *Signed by :* W. H. Simmons, R. Stern.

Wluka, David Jankiel. Australian. Oriel College, Oxford. Research Student. *Signed by :* D. Willis, D. J. Voaden.

Wood, Keith Henry. British. 133, Wincheap, Canterbury, Kent. Student at Battersea Polytechnic. *Signed by :* J. E. Salmon, V. S. Griffiths.

UNDER SPECIAL PROVISION APPERTAINING TO CANDIDATES RESIDENT ABROAD.

Anwer, Mehkeri K. Pakistani. 2182, Pir Illahi Bux Colony, Karachi 5, Pakistan. Student. *Signed by :* A. Kamal.

Inokuchi, Hiroo, D.Sc. (Tokyo). Japanese. c/o Miss M. Griffin, 4 Newcastle Avenue, Devonshire Avenue, Beeston, Notts. Japanese Ramsay Fellow. *Signed by :* D. D. Eley.

Lucier, John J., M.S. and Ph.D. (Western Reserve University). American. 300 College Park Avenue, Dayton 9, Ohio, U.S.A. Assistant Professor at Dayton University. *Signed by :* R. J. Morath.

Massin, Hyman Dave, B.S. (The Rice Institute). American. The Texas Company, P.O. Box 1499, Port Arthur, Texas, U.S.A. Director of Research. *Signed by :* C. E. Lauer.

Savur, Gopal Rao. Hindu. 15-E, Shivaji Park, Bombay-28, India. Research Director of Pectin Manufacturing Co., Bhandup, Bombay. *Signed by :* K. Venkataraman.

PAPERS ACCEPTED

(List of Papers accepted between September 28th, 1955, and October 25th, 1955, for publication in the *Journal*.)

"The thermal decomposition of lead dioxide in air." By GEORGE BUTLER and J. L. COPP.

"Studies in hydrogen-bond formation. Part IV. The hydrogen-bonding properties of water in non-aqueous solution and of alcohols, aldehydes, simple carbohydrates, ketones, phenols, and quinones in aqueous and non-aqueous solutions." By F. M. ARSHID, C. H. GILES, and S. K. JAIN.

"The effect of dissolved oxygen on the diamagnetic susceptibility of organic liquids." By C. M. FRENCH and D. HARRISON.

"The stability of H_2^+ and OH^+ in aqueous solutions." By C. A. COULSON.

"The conductivity of silver nitrate in non-aqueous and mixed solvents. Part IV." By V. S. GRIFFITHS and K. S. LAWRENCE.

"The interaction of *aldehydo*-sugars and primary aromatic amines." By J. L. BARCLAY, A. B. FOSTER, and W. G. OVEREND.

"The stereochemistry of sesquiethylenediaminetrimethylplatinic iodide." By MARY R. TRUTER and (in part) E. G. COX.

"Specific-conductivity measurements directly related to solubilities with special reference to calcium sulphate (anhydrite) solutions." By W. M. MADGIN and D. A. SWALES.

"The stereochemistry of organic derivatives of phosphorus. Part III. The synthesis and optical resolution of a spirocyclic phosphonium salt possessing molecular dissymmetry." By F. A. HART and FREDERICK G. MANN.

"Organic complex-forming agents for metals. Part I. Preparation of 4-hydroxy- and 4 : 7-dihydroxy-benziminazoles and related compounds." By E. S. LANE and C. WILLIAMS.

"Triterpenoids. Part XLVI. The conversion of ursa-8(11) : 12-dien-3-one into oleana-11 : 13(18)-dien-3-one." By J. I. SHAW, F. S. SPRING, and ROBERT STEVENSON.

"1-Phenylnaphthalenes. Part III. The effect of substituents and their position on the absorption spectra of 1-phenylnaphthalene-2 : 3-dicarboxylic anhydrides." By F. G. BADDAR and ZAKI SAWIRES.

"Perfluoroalkyl compounds of nitrogen. Part II. The vibrational assignment of trifluoronitrosomethane." By MRS. J. MASON (MISS J. BANUS) and J. DUNDERDALE.

"Perfluoroalkyl compounds of nitrogen. Part III. The vibrational assignment of fluoropicrin, chloropicrin, and bromopicrin." By MRS. J. MASON (MISS J. BANUS) and J. DUNDERDALE.

"Reactions of substituted 3 : 4-dihydro-4-oxoquinazolines with Grignard reagents." By I. K. KACKER and S. HUSAIN ZAHEER.

"16-Oxo- and 16α-hydroxy-testosterone." By (MRS.) W. J. ADAMS, D. K. PATEL, V. PETROW, and (MRS.) I. A. STUART-WEBB.

"Structural and stereochemical investigations of cyclic bases. Part I. 3-(Tertiary amino)-steroids." By B. B. GENT and J. MCKENNA.

"The reaction between *tert.*-butyl chloride and sodium thiophenoxide." By P. B. D. DE LA MARE and C. A. VERNON.

"Deoxypentose nucleic acids. Part VII. A re-examination of the titration curves of sodium deoxyribonucleate." By D. O. JORDAN, A. R. MATHIESON, and SHEILA MATTY.

"Deoxypentose nucleic acids. Part VIII. The influence of concentration and ionic strength on the electrometric titration of sodium deoxyribonucleate." By D. O. JORDAN, A. R. MATHIESON, and SHEILA MATTY.

"Deoxypentose nucleic acids. Part IX. The electrophoretic mobility of sodium deoxyribonucleate at various pH values and ionic strengths." By A. R. MATHIESON and J. V. MCLAREN.

"Dambonitol. Part II. Oxidation by periodic acid and sodium metaperiodate." By A. K. KIANG and K. H. LOKE.

" Anhydro-compounds from nitrogen-containing derivatives of thioglycollic acid. Part II. Glyoxaline and benziminazole compounds." By J. D. KENDALL.

" The search for chemotherapeutic amidines. Part XII. *NN'*-Di(amidinophenyl)-amidines." By E. CRUNDWELL.

" Reactions of *N*-carboxy-α-amino-acid anhydrides catalysed by tertiary bases." By D. G. H. BALLARD and C. H. BAMFORD.

" The relative stabilising influence of substituents on free alkyl radicals. Part I. The addition of bromotrichloromethane and butanal to unsaturated acids, esters, and nitriles." By R. L. HUANG.

" Polarography in fused salts. The dipping platinum microelectrode." By S. N. FLENGAS.

" Synthesis of polycyclic compounds. Part II. The ring closure of β-carboxy-γ-1-naphthylbutyric acid." By J. C. BARDHAN, D. NASIPURI, and R. N. ADHYA.

" Compounds of potential pharmacological interest. Part II. Acyl derivatives of 1-amino-3-phenylindane." By P. G. PHILPOTT and J. A. BARLTROP.

" Perfluoroalkyl derivatives of sulphur. Part IV. Perfluoroalkanesulphonic acids." By T. GRAMSTAD and R. N. HASZELDINE.

" The condensation of acridone with tertiary aromatic amines, and the ultraviolet absorption spectra of the products." By R. M. ACHESON and M. J. T. ROBINSON.

" Peptides. Part V. Condensation of the γ-carboxyl group of α-glutamyl peptides with the peptide chain." By D. W. CLAYTON, G. W. KENNER, and R. C. SHEPPARD.

" Oxidation of organic sulphides. Part V. The products of the reaction of organic hydroperoxides with alk-2-enyl sulphides." By D. BARNARD.

" A spectrophotometric study of hexanitrodiphenylamine. Part I. The molecular and ionic forms in dioxan." By S. KERTES and J. M. E. GOLDSCHMIDT.

" Syntheses of hydrocarbons possibly related to carcinogenic factors in city smoke." By G. R. CLEMO and N. D. GHATGE.

" The thermochemistry of organic phosphorus compounds. Part II. Ester and anilide formation from halides, and combustion of the anilides." By E. NEALE, L. T. D. WILLIAMS, and (in part) V. T. MOORES.

" Alkyl sulphates. Part I. Critical micelle concentrations of the sodium salts." By H. C. EVANS.

" Ionisation equilibria of metal co-ordination complexes in benzene solutions. Part II. The structures of some cuprous complexes." By A. R. BURKIN.

" The formation and reductive scission of bis-compounds from enols." By WILLIAM BRADLEY and LEONARD J. WATKINSON.

" The latent heat of vaporization and the thermochemistry of ethyl nitrate." By PETER GRAY, M. W. T. PRATT, and M. J. LARKIN.

" Decahydro*iso*quinolines and related compounds. Part I. Some 6-oxygenated derivatives and an example of abnormal ultraviolet absorption." By ALAN MARCHANT and A. R. PINDER.

" A new method of preparation of aryl *iso*thiocyanates." By J. N. BAXTER, J. CYMERMAN-CRAIG, M. MOYLE, and R. A. WHITE.

" Polyfluoroalkyl compounds of silicon. Part I. The reaction of trichlorosilane with tetrafluoroethylene." By R. N. HASZELDINE and R. J. MARKLOW.

" The reversibility of the adsorption of catalyst poisons. Part IV. Revival of poisoned catalysts by gas-phase desorption." By E. B. MAXTED and M. JOSEPHS.

" The mechanism of hydrolysis of acid chlorides. Part VI. Formolysis of *p*-substituted benzoyl chlorides." By E. W. CRUNDEN and R. F. HUDSON.

" Saponins and sapogenins. Part IV. Agapanthagenin (22*a*-spirostan-2α : 3β : 5α-triol), a new sapogenin from Agapanthus species." By MRS. T. STEPHEN.

" Exchange reactions and magnetic susceptibilities of complex salts. Part IV. Correlation with absorption spectra." By H. C. CLARK and A. L. ODELL.

" The constitution and synthesis of fuscin." By D. H. R. BARTON and J. B. HENDRICKSON.

" Aromatic azo-compounds. Part VIII. A study of intramolecular hydrogen bonding in 8-hydroxyquinoline." By G. M. BADGER and R. G. BUTTERY.

" Carbohydrates of the roots of the parsnip, *Pastinaca sativa*." By D. M. W. ANDERSON and C. T. GREENWOOD.

" Ion-exchange studies of phosphates. Part I. Ion-exchange sorption and pH-titration methods for detection of complex formation." By A. HOLROYD and J. E. SALMON.

" Peroxides as initiators of polymerization of methyl methacrylate." By (the late) N. G. SAHA, U. S. NANDI, and SANTI R. PALIT.

" Synthetic applications of activated metal catalysts. Part II. The formation of heterocyclic diaryls." By G. M. BADGER and W. H. F. SASSE.

" The reaction of di(2-chloroethyl) ether with hydrazine." By W. V. FARRAR.

" Trichloromethyl sulphones and related compounds." By W. V. FARRAR.

" Infrared absorption of halogeno-steroids." By D. H. R. BARTON, J. E. PAGE, and C. W. SHOPPEE.

" Equilibria between *cis*- and *trans*-$[(MR_3)_2PtX_2]$ (where M = P, As, and Sb : X = halogen)." By J. CHATT and R. G. WILKINS.

" Mechanism of aromatic side-chain reactions with special reference to the polar effects of substituents. Part XVI. Hyperconjugation of groups of the type CH_2X in the benzaldehyde–cyanohydrin equilibria." By John W. BAKER, J. A. L. BRIEUX, and D. G. SAUNDERS.

" The disulphones derived by oxidation of the diethyl dithioacetals of D-galatose, D-mannose, and D-glucose with peroxypropionic acid, and their conversion into aldopentoses." By L. HOUGH and T. J. TAYLOR.

" A novel method of cyanoethylation. Part IV. Substitution effects." By R. J. BATES, J. CYMERMAN-CRAIG, M. MOYLE, and R. J. YOUNG.

" Naphthyridines. Part III. Hydroxynaphthyridines." By E. P. HART.

" The oxidation of some 3 : 4-Dihydroxyphenethylamines." By E. J. FORBES.

" A quantitative study of the autoxidation products of oleic acid." By GEORGE KING.

" Cationic polymerisation of oxa*cyclo*butanes : Part I." By J. B. ROSE.

" Cationic polymerisation of oxa*cyclo*butanes. Part II." By J. B. ROSE.

" Synthesis of polycyclic compounds. Part I. A new synthesis of alkylphenanthrenes." By J. C. BARDHAN and D. NASIPURI.

" The constituents of high-boiling petroleum distillates. Part III. Anthracene homologues in a Kuwait oil." By W. CARRUTHERS.

" Steric relations between ionisation of aralkyl chlorides and dissociation of anilinium ions. Part II." By G. BADDELEY, J. CHADWICK, and H. T. TAYLOR.

" Steric relations between ionisation of aralkyl chlorides and dissociation of anilinium ions. Part III." By G. BADDELEY, J. CHADWICK, and H. T. TAYLOR.

" The kinetics of the reaction between cobalt(III) and thallium(I) in aqueous perchloric acid." By K. G. ASHURST and W. C. E. HIGGINSON.

" Solutions in sulphuric acid. Part XIX. A conductometric investigation of the ionisation of some carboxylic anhydrides." By R. FLOWERS, R. J. GILLESPIE, and S. WASIF.

" Perfluorodecahydroquinoline and perfluorotetradecahydroanthracene." By R. N. HASZELDINE and F. SMITH.

" The isolation of octadeca-8 : 10 : 12-trienoic acid from marigold-seed oil." By JOHN MCLEAN and A. H. CLARK.

" Adsorption of binary liquid mixtures on solid adsorbents." By G. S. MILL."

" Partial reduction of steroid hormones and related substances. Part II. A new synthetical route to steroidal 20 : 21-ketols." By J. K. NORYMBERSKI.

" Steroids and Walden inversion. Part XXVII. 3α-Cholesterylamine and coprostan-3α-yl amine." By H. C. RICHARDS, C. W. SHOPPEE, J. C. P. SLY, and C. H. R. SUMMERS.

" The synthesis of usnic acid." By D. H. R. BARTON, A. M. DEFLORIN, and O. E. EDWARDS.

" Reaction of tellurium dioxide and selenium tetrafluoride : preparation of tellurium tetrafluoride." By R. CAMPBELL and P. L. ROBINSON.

" Preparation and some properties of 2 : 2′-dibromodiphenylamine." By EMRYS R. H. JONES and FREDERICK G. MANN.

" The conversion of bulbocapnine into morphothebaine." By W. A. AYER and W. I. TAYLOR.

" The oxidation of aromatic primary amines with benzoyl peroxide." By J. T. EDWARD.

" Steroids and Walden inversion. Part XXVIII. The structure of the lactonic acid derived from 6α-hydroxy-2 : 3-*seco*cholestane-2 : 3-dioic acid." By D. R. JAMES and C. W. SHOPPEE.

" The optical stability of 1 : 2 : 3 : 4-tetrahydro-2-naphthylamine." By A. G. DAVIES, E. E. EDWIN, and J. KENYON.

" The dissociation constant of the ion-pair $Co(NH_3)_6^{3+}OH^-$." By J. A. CATON and J. E. PRUE.

" Triterpenoids. Part XXI. A triterpenoid lactone from petroleum." By D. H. R. BARTON, W. CARRUTHERS, and K. H. OVERTON.

" Interaction of Lewis acids with aromatic hydrocarbons and bases. Part XVI. The association of chloranil with methylbenzenes in *cyclo*hexane." By R. FOSTER, D. LL. HAMMICK, and B. N. PARSONS.

" Modified steroid hormones. Part I. Some 4-bromo-3-oxo-Δ^4-derivatives." By D. N. KIRK, D. K. PATEL, and V. PETROW.

" Experiments on the preparation of indolocarbazoles. Part VIII. The preparation of 1-methylindolo(2′ : 3′-2 : 3)carbazole." By MARGARET L. SWINDELLS and MURIEL L. TOMLINSON.

" Chemical examination of *Wedelia calendulacea*. Part I. Structure of wedelolactone." By T. R. GOVINDACHARI, K. MAGARAJAN, and B. R. PAI.

" Deoxy-sugars. Part XXX. Synthesis and characterization of derivatives of 2-deoxy*aldehydo*-D-galactose and its 2-deoxy-D-glucose analogue." By J. L. BARCLAY, A. J. CLEAVER, A. B. FOSTER, and W. G. OVEREND.

" Some derivatives of *cis*-1 : 2 : 3 : 4 : 9 : 10 : 11 : 12-octahydrophenazine." By PATRICIA J. EARLE and MURIEL L. TOMLINSON.

" Some derivatives of chroman-4-one." By RITA A. GREGORY and MURIEL L. TOMLINSON.

ADDITIONS TO THE LIBRARY

Items marked with an asterisk (*) are for reference only. Otherwise the following books will be available for loan after November 24th, 1955.

*BLÜCHER, H. Auskunftsbuch für die chemische industrie. 18th ed. 1954. de Gruyter. £8 11*s.* 6*d.*

EMMETT, P. H. (Ed.). Catalysis. Vol. 3. Hydrogenation and dehydrogenation. 1955. Reinhold. £5.

GINSBERG, H. Leichtmetallanalyse. 3rd ed. 1955. de Gruyter. £1 3*s.* 6*d.*

LAVOISIER, A. L. Oeuvres de Lavoisier. Correspondance, recueillie et annotée par René Fric. Fasc. 1, 1763—1769. 1955. Albin Michel. £2 15*s.*

WEST VIRGINIA PULP AND PAPER COMPANY. INDUSTRIAL CHEMICAL SALES DIVISION. Taste and odor control in water purification. 1955.

(Presented by the Company.)

LOCAL REPRESENTATIVES OF THE CHEMICAL SOCIETY

Aberdeen.	R. H. Thomson, Ph.D., F.R.I.C., Chemistry Department, The University, Old Aberdeen.
Australia.	Dr. K. H. Pausacker, Chemistry Department, University of Melbourne, Carlton, N. 3, Victoria, Australia.
Birmingham.	J. C. Tatlow, B.Sc., Ph.D., Department of Chemistry, The University, Edgbaston, Birmingham, 15.
Bristol.	P. Woodward, B.Sc., Ph.D., Chemistry Department, The University, Woodland Road, Bristol.
Cambridge.	R. N. Haszeldine, B.Sc., M.A., Ph.D., University Chemical Laboratory, Pembroke Street, Cambridge.
Canada.	Professor J. K. N. Jones, M.Sc., Ph.D., A.R.I.C., Queen's University, Kingston, Ontario.
Ceylon.	M. U. S. Sultanbawa, B.Sc., Ph.D., A.R.I.C., Department of Chemistry, The University, Colombo, Ceylon.
Edinburgh.	G. O. Aspinall, B.Sc., Ph.D., Chemistry Department, King's Buildings, West Mains Road, Edinburgh.
Exeter.	K. Schofield, B.Sc., Ph.D., F.R.I.C., Department of Chemistry, Washington Singer Laboratories, Prince of Wales' Road, Exeter.
Glasgow.	D. S. Payne, B.Sc., Ph.D., A.R.I.C. Chemistry Department, The University, Glasgow, W.2.
Hull.	G. W. Gray, B.Sc, Ph.D., Chemistry Department, The University, Hull.
India.	Professor T. R. Seshadri, M.A., Ph.D., F.R.I.C., Department of Chemistry, The University, Delhi, India.
Irish Republic.	D. O'Tuama, M.Sc., Ph.D., F.I.C.I., Medical Research Council of Ireland, The Laboratories, Trinity College, Dublin.
Leeds.	E. Rothstein, Ph.D., D.Sc., A.R.C.S., Organic Chemistry Department, The University, Leeds, 2.
Liverpool.	A. K. Holliday, B.Sc., Ph.D., Department of Physical and Inorganic Chemistry, The University, Liverpool.
,,	D. W. Broad, Ph.D., A.R.I.C., Imperial Chemical Industries Limited, Research Department, Widnes Laboratory, Widnes.
Manchester.	G. R. Barker, B.Sc., Ph.D., Chemistry Department, The University, Manchester, 13.
,,	A. C. Farthing, M.A., B.Sc., Imperial Chemical Industries Limited, Hexagon House, Blackley, Manchester, 9.
Newcastle and Durham.	G. A. Swan, D.Sc., Ph.D., F.R.I.C., Department of Chemistry, King's College, Newcastle-on-Tyne, 1.
New Zealand.	Professor S. N. Slater, M.Sc., D.Phil., A.R.I.C., Chemistry Department, Victoria University College, Wellington, New Zealand.
Northern Ireland.	R. G. R. Bacon, PhD., A.R.C.S., Chemistry Department, Queen's University, Belfast.
North Wales.	J. E. McKail, Ph.D., Department of Chemistry, University College of North Wales, Bangor.
Nottingham.	C. C. Addison, D.Sc., Ph.D., F.R.I.C., Chemistry Department, The University, University Park, Nottingham.
Oxford.	L. A. K. Staveley, M.A., Inorganic Chemistry Laboratory, South Parks Road, Oxford.
Pakistan.	M. I. D. Chughtai, M.Sc.Tech., Ph.D., A.R.I.C., Punjab University Institute of Chemistry, The Mall, Lahore, Pakistan.
St. Andrews and Dundee.	C. Horrex, M.Sc., Ph.D., Chemistry Department, The University, St. Andrews.
Sheffield.	H. J. V. Tyrrell, M.A., B.Sc., Chemistry Department, The University, Sheffield, 10.
South Africa.	Professor F. L. Warren, Ph.D., F.R.I.C., Department of Chemistry, University of Natal, P.O. Box 375, Pietermaritzburg, South Africa.
Southampton.	N. B. Chapman, M.A., Ph.D., Department of Chemistry, The University, Southampton.
South Wales.	K. W. Sykes, M.A., B.Sc., D.Phil., Department of Chemistry, University College, Singleton Park, Swansea.

PROCEEDINGS

OF THE

CHEMICAL SOCIETY

SCIENTIFIC MEETINGS DURING FEBRUARY, 1956

LONDON.

Thursday, February 2nd, 1956, at 2.30 p.m. and *7.30 p.m.*

Symposium, **Recent Advances in the Chemistry of Colouring Matters,** arranged by Professor E. A. Braude, D.Sc., F.R.I.C. To be held in the Lecture Theatre, The Royal Institution, Albemarle Street, W.1.

Thursday, February 16th, 1956, at 7.30 p.m.

Meeting for the Reading of Original Papers. To be held in the Rooms of the Society, Burlington House, W.1.

ABERDEEN.

Friday, February 3rd, 1956, at 7.30 p.m.

Lecture, **Analytical Chemistry, Chemical Analysis and the Analyst,** by Mr. R. C. Chirnside, F.R.I.C. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry, to be held at Marischal College.

BIRMINGHAM.

Friday, February 10th, 1956, at 4.30 p.m.

Lecture, **Ionisation of Acids and Bases,** by Professor D. H. Everett, M.B.E., M.A., D.Phil. Joint Meeting with Birmingham University Chemical Society to be held in the Chemistry Department, The University.

Friday, February 24th, 1956, at 4.30 p.m.

Lecture, **Some Radiation Problems in Nuclear Energy Research,** by Dr. W. Wild. Joint Meeting with Birmingham University Chemical Society to be held in the Chemistry Department, The University.

BRISTOL.

Thursday, February 2nd, 1956, at 5.15 p.m.

Lecture, **Operational Research,** by Mr. D. Hicks. Joint Meeting with the Student Chemical Society to be held in the Chemistry Department, The University.

Thursday, February 9th, 1956, at 7.0 p.m.

Lecture, **Recent Advances in Acetylene Chemistry,** by Professor R. A. Raphael, Ph.D., A.R.I.C. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry, to be held in the Chemistry Department, The University.

Thursday, February 16th, 1956, at 5.15 p.m.

Lecture, **Some Aspects of Research in the Glass Industry,** by Mr. W. J. R. Merren. Joint Meeting with the Student Chemical Society to be held in the Chemistry Department, The University.

CAMBRIDGE.

Friday, February 10th, 1956, at 8.30 p.m.

Lecture, **Nuclear Resonance Spectroscopy,** by Dr. R. Richards. Joint Meeting with the University Chemical Society to be held in the University Chemical Laboratory, Pembroke Street.

EDINBURGH.

Tuesday, February 7th, 1956, at 7.0 p.m.

Lecture, **Organometallic Co-ordination Compounds,** by Professor G. E. Coates, M.A., D.Sc., F.R.I.C. Joint Meeting with the Royal Institute of Chemistry, Society of Chemical Industry, and Edinburgh University Chemical Society, to be held in the Biochemistry Lecture Theatre, Teviot Place.

Thursday, February 23rd, 1956, at 7.30 p.m.

Tilden Lecture, **Some Developments in the Study of Physical Adsorption,** by Professor D. H. Everett, M.B.E., M.A., D.Phil. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry, to be held at the North British Station Hotel.

EXETER.

Friday, February 3rd, 1956, at 5.0 p.m.

Lecture, **Some Stereochemical Problems,** by Professor E. E. Turner, M.A., D.Sc., F.R.I.C., F.R.S. To be given in the Washington Singer Laboratories.

GLASGOW.

Friday, February 17th, 1956, at 7.0 p.m.

Annual General Meeting of local Fellows, followed by Lecture entitled **Some Recent Developments in the Chemistry of the Vitamins D,** by Professor B. Lythgoe, M.A., Ph.D. To be held at the Royal Technical College, Glasgow, C.1.

HULL.

Thursday, February 2nd, 1956, at 6.0 p.m.

Lecture, **Designing New Rubber-like Polymers,** by Professor G. Gee, M.Sc., Ph.D., F.R.S. To be given in the Chemistry Department, The University.

IRISH REPUBLIC.

Wednesday, February 22nd, 1956, at 7.45 p.m.

Lecture, **A Fluorocarbon Chemistry,** by Dr. R. N. Haszeldine, M.A. To be given in the University Chemical Laboratory, Trinity College, Dublin.

LEEDS.

Thursday, February 2nd, 1956, at 6.30 p.m.

Royal Institute of Chemistry Lecture, **Colour,** by Dr. T. Vickerstaff, M.Sc., F.R.I.C. To be given in the Chemistry Lecture Theatre, The University. (All Fellows are invited.)

Monday, February 13th, 1956, at 6.30 p.m.

Royal Institute of Chemistry Lecture, **The Development of Industrial Toxicology,** by Dr. J. C. Gage, B.Sc., F.R.I.C. To be given in the Chemistry Lecture Theatre, The University. (All Fellows are invited.)

MANCHESTER.

Thursday, February 9th, 1956, at 6.30 p.m.

Official Meeting and Tilden Lecture entitled **Recent Progress in the Chemistry of Peptides,** by Dr. G. W. Kenner, M.Sc. To be held in the Large Chemistry Theatre, The University.

NEWCASTLE AND DURHAM.

Correction

The title of the Bedson Club Lecture to be given by Dr. F. Sanger on January 27th, 1956, is **The Chemistry of Insulin.**

Friday, February 17th, 1956, at 5.30 p.m.

Tilden Lecture, **Recent Progress in the Chemistry of Peptides,** by Dr. G. W. Kenner, M.Sc. To be given in the Chemistry Building, King's College, Newcastle upon Tyne, 1.

NORTHERN IRELAND.

Thursday, February 9th, 1956, at 7.45 p.m.

Lecture, **Reactions in Liquid Dinitrogen Tetroxide**, by Dr. C. C. Addison. F.Inst.P., F.R.I.C. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry, to be held at The Queen's University, Belfast.

Tuesday, February 21st, 1956, at 7.15 p.m.

Lecture, **The Fischer–Tropsch Synthesis. A Challenge to the Physical Chemist,** by Professor C. Kemball, M.A., Ph.D., F.R.I.C. Joint Meeting with the Royal Institute of Chemistry and the Society of Chemical Industry, to be held at The Queen's University, Belfast.

NORTH WALES.

Thursday, February 23rd, 1956, at 5.15 p.m.

Lecture, **Some Aspects of the Organic Chemistry of Phosphorus,** by Professor H. N. Rydon, Ph.D., D.Sc., F.R.I.C. Joint Meeting with the University College of Wales Chemical Society to be held at the Edward Davies Chemical Laboratories, Aberystwyth.

NOTTINGHAM.

Thursday, February 9th, 1956, at 4.5 p.m.

Lecture by Professor B. Lythgoe, M.A., Ph.D. Joint Meeting with the University of Nottingham Chemical Society to be held at The University.

OXFORD.

Monday, February 6th, 1956, at 8.15 p.m.

Lecture, **Gas–Liquid Chromatography,** by Dr. A. T. James, B.Sc. Joint Meeting with the Royal Institute of Chemistry and the Oxford University Alembic Club, to be held in the Physical Chemistry Laboratory, South Parks Road, Oxford.

Monday, February, 20th, 1956, at 8.15 p.m.

Lecture, **Steroid Hormones, Natural and Artificial,** by Professor C. W. Shoppee, Ph.D., D.Sc., F.R.I.C. Joint Meeting with the Oxford University Alembic Club to be held in the Physical Chemistry Laboratory, South Parks Road, Oxford.

ST. ANDREWS AND DUNDEE.

Thursday, February 9th, 1956, at 5.0 p.m.

Lecture, **Polymerisation Reactions in Solution,** by Professor G. M. Burnett, D.Sc., Ph.D. Joint Meeting with the University Chemical Society to be held in the Chemistry Department, Queen's College, Dundee.

Friday, February 10th, 1956, at 5.15 p.m.

Lecture, **Some Recent Studies in Organometallic Compounds,** by Professor G. E. Coates, M.A., D.Sc., F.R.I.C. Joint Meeting with the University Chemical Society and the Royal Institute of Chemistry, to be held in the Chemistry Department, St. Salvators College, St. Andrews.

SHEFFIELD.

Thursday, February 2nd, 1956, at 7.30 p.m.

Lecture, **Chemical Aspects of Nucleotide Biosynthesis,** by Professor J. Baddiley, M.Sc., Ph.D. Joint Meeting with the University Chemical Society to be held in the Chemistry Lecture Theatre, The University.

SOUTHAMPTON.

Friday, February 3rd, 1956, at 5.0 p.m.

Lecture, **Magnetism and the Structure of Inorganic Molecules,** by Professor R. S. Nyholm, D.Sc., A.R.I.C. Joint Meeting with Southampton University Chemical Society to be held in the Chemistry Department, The University.

SOUTH WALES.

Friday, February 3rd, 1956, at 6.0 p.m. (Postponed from January 27th.)

Lecture, **The Actinide Elements,** by Mr. H. A. C. McKay, B.A. Joint Meeting with the Royal Institute of Chemistry to be held in the Chemistry Department, University College, Swansea.

Monday, February 20th, 1956, at 5.30 p.m.

Lecture, **The Hydride Ion in Organic Chemistry**, by Professor E. A. Braude, Ph.D., D.Sc., F.R.I.C. To be given in the Chemistry Department, University College, Cardiff.

OFFICIAL ANNOUNCEMENTS

DEATHS.

The Council regrets to announce the deaths of the following Fellows :

	Elected.	Died.
Alan Hugh Boud (London, W.12)	Apr. 4th, 1946.	Mar. 28th, 1955.
Thomas Francis Doyle (Dublin)	Feb. 20th, 1936.	May 29th, 1955.
Thomas Ewan (Strathblane)	Feb. 20th, 1896.	Sept. 4th, 1955.
Duncan Hunter (Nottingham)	Dec. 5th, 1929.	Oct. 18th, 1955.
William Jay Schieffelin (New York)	Dec. 6th, 1888.	Apr. 29th, 1955.

CONGRATULATIONS.

The President has conveyed the congratulations of the Society to Professor Vincent du Vigneaud, who has been awarded a Nobel Prize for Chemistry.

Congratulations have also been conveyed to the following Fellows on the award of Medals announced by the Royal Society :

Royal Medal.
Sir Alexander Todd.
Davy Medal.
Professor H. W. Melville.

ACKNOWLEDGMENTS.

Acknowledgment is made of gifts of the Society's publications from Mr. F. O. Isaac and Mr. A. Lowe.

ELECTION OF NEW FELLOWS.

The following 21 candidates were elected Fellows of the Society on November 17th, 1955 :

Theodore Immanuel Bieber.
Stanley Morton Bloom.
Joseph Patrick Brown.
Alan George Cooper.
Marianne Davies.
Ivan Dunstan.
Allan Walter Goulding.
Margaret Eden Hey.
Peter Edwin Horn.
Tom Bellerby Howard.
Wilson Samuel Kao.
John Frank Largier.
John Gerard McGovern.
David George Hovell Marsden.
Peter John May.
Philip Maurice Phillips.
Richard C. Thamm.
Monica Sylvia Webster (Mrs.).
John Herbert Williams.
Philip Douglas Wingfield.
William Woodwark.

VACANCIES ON COUNCIL.

In accordance with the Bye-Laws, the following vacant places on the Council fall due to be filled at the Annual General Meeting to be held in Nottingham on Tuesday, March 27th, 1956.

Office.	*No. of Vacancies.*	*Names of Members who are to retire.*
President	ONE	Professor W. Wardlaw
Honorary Secretary	ONE	Professor E. D. Hughes
Vice-Presidents who have filled the Office of President	ONE	Sir Robert Robinson
Vice-Presidents who have not filled the Office of President	ONE	Professor R. D. Haworth
Elected Ordinary Members of Council :		
Constituency I (South-East England)	FOUR	Professor M. J. S. Dewar Dr. G. W. Kenner Dr. A. Maccoll Dr. A. I. Vogel
Constituency II (Central and South-West England and South Wales)	ONE	Dr. E. J. Bourne
Constituency IV (North-East England)	TWO	Dr. I. J. Faulkner Professor Brynmor Jones

With the exception of Dr. G. W. Kenner and Dr. A. Maccoll, who were appointed under Bye-Law 42, the members who are to retire are not eligible for re-election to the same Office until a lapse of one year.

No vacancies arise in Constituencies III, V, and VI.

In accordance with Bye-Law 46, Professor W. Wardlaw becomes a Vice-President who has filled the Office of President. In accordance with Bye-Law 24, the Council has nominated Professor E. L. Hirst as President, and Dr. J. Chatt as Honorary Secretary. Nominations by Fellows for the Offices of President, Vice-President who has not filled the Office of President, and Honorary Secretary should be made in writing and must be *signed by at least twenty Fellows.*

Fellows resident in a constituency may nominate any Fellow resident in that constituency for election to the Council to fill a vacancy among Elected Ordinary Members of Council allotted to that constituency. Every such nomination must be in writing *signed by at least fifteen Fellows resident in that constituency.*

Fellows may obtain forms of nomination from the General Secretary and should state the vacancy for which they are requested. Every nomination must relate to one vacant place only, and must be accompanied by a signed declaration by the nominee that he is willing to accept office, if elected. Nominations must be received by the Society not later than Tuesday, February 14th, 1956.

LOCAL REPRESENTATIVES.

Dr. K. H. Pausacker has been appointed Local Representative in Australia in succession to Professor A. J. Birch.

QUARTERLY REVIEWS.

Quarterly Reviews, Vol. IX, No. 4, will contain the following articles :

" The action of ionising radiations on organic compounds," by E. Collinson and A. J. Swallow.

" The tetracyclic triterpenes," by R. M. Gascoigne and J. J. H. Simes.

" Structure and reactivity in the nitrogen dioxide–dinitrogen tetroxide system," by P. Gray and A. D. Yoffe.

" Ferrocene and related compounds," by P. L. Pauson.

It is expected that forthcoming issues will contain the following articles :

" The indole alkaloids excluding harmine and strychnine," by J. E. Saxton.

" The properties and nature of adsorbent carbons," by J. J. Kipling.

" The principles of conformational analysis," by D. H. R. Barton and R. C. Cookson.

" Phenol tautomerism," by R. H. Thomson.

VAN'T HOFF FUND.

The Committee of the Van't Hoff Fund for the endowment of investigations in the field of pure and applied chemistry invites applications for grants from the fund.

The amount available for 1956 is about 1500 Dutch guilders, and application should be sent by registered post to Het Bestuur der Koninklijke Nederlandse Academie voor Wetenscheppen, bestemd voor de Commissie van het " Van't Hoff Fonds," Trippenhuis, Kloveniersburgwal 29, Amsterdam, before March 1st, 1956. Applicants must state the amount of the grant desired and the purpose for which it is required.

MINUTES OF SCIENTIFIC MEETINGS

Minutes of a

SCIENTIFIC MEETING

held at Burlington House on Thursday, 3rd November, 1955, at 4 p.m.

The President, Professor W. Wardlaw, C.B.E., D.Sc., F.R.I.C., was in the Chair.

MINUTES.

The Minutes of the Scientific Meetings held at the Institution of Civil Engineers on October 20th, and at the University of Glasgow, on October 28th, 1955, were read, and were confirmed and signed.

FORMAL ADMISSION OF FELLOWS.

The following were admitted Fellows of the Society: M. E. U. Taylor, J. S. G. Cox, D. Casson.

SCIENTIFIC COMMUNICATIONS.

The following papers were read and discussed:

"Galloflavin. Part III. The Position of the Carboxyl Group in *iso*Galloflavin and a Synthesis of Trimethybrevifolin." By J. Grimshaw and R. D. Haworth.

"The Chemistry of Extractives from Hardwoods. Part XXVI. Experiments on *cyclo*Eucalenol a new Triterpene from *Eucalyptus microcorys*." By J. S. G. Cox, F. E. King, and T. J. King.

"The Synthesis of Some Fungal Metabolites." By D. H. R. Barton, A. M. Deflorin, O. E. Edwards, and J. B. Henderson.

Minutes of a

SCIENTIFIC MEETING

held at the Imperial College of Science and Technology, London, S.W.7, on Thursday, November 17th, 1955, at 7.30 p.m.

The President, Professor W. Wardlaw, C.B.E., D.Sc., F.R.I.C., was in the Chair.

MINUTES.

The Minutes of the meeting held at Burlington House on Thursday, November 3rd, 1955, were read, and were confirmed and signed.

FORMAL ADMISSION OF FELLOWS.

The following were admitted Fellows of the Society: A. D. Leach, N. H. Davies, P. Bechman, David Feakins.

TILDEN LECTURE.

After a brief introduction, the President called upon Professor D. H. Everett, M.B.E., D.Phil., to deliver the Tilden Lecture entitled "Some Developments in the Study of Physical Adsorption." At the conclusion of the Lecture a vote of thanks to Professor Everett, proposed by the President, was carried with acclamation.

LIST OF APPLICATIONS FOR FELLOWSHIP

(Fellows wishing to lodge objection to the election of these candidates should communicate with the Honorary Secretaries within ten days of the date of publication of the Journal *for December, 1955. Such objections will be treated as confidential. The forms of application are available in the Library.)*

Applequist, Douglas Einar, B.S. (California), Ph.D. (Calif. Inst. Tech.). American. Noyes Chemical Laboratory, University of Illinois, Urbana, Illinois, U.S.A. Instructor in Organic Chemistry. *Signed by :* D. Y. Curtin, K. L. Rinehart.

Baldrey, John Arthur, B.Sc. and Ph.D. (Lond.). British. 211, London Road, Bedford. Research Chemist with Albright and Wilson, Ltd. *Signed by :* D. P. Elias, D. E. C. Corbridge.

Barben, Ian Knowles, B.Sc. (Lond.). British. 52, Hall Lane, Farnworth, Nr. Bolton, Lancs. Research Student at Salford Technical College. *Signed by :* H. Suschitzky, G. R. Ramage.

Bird, John Bolton. British. 10, The Greenway, Rayner's Lane, Pinner, Middlesex. Student. *Signed by :* J. Honeyman, D. Bryce-Smith.

Brownstein, Sydney Kenneth, B.A. (Saskatchewan), Ph.D. (Chicago). Canadian. 79, Connaught Crescent, Regina, Saskatchewan, Canada. National Research Council (Canada) Fellow. *Signed by :* C. A. Bunton, E. D. Hughes.

Campaigne, Ernest E., M.S. and Ph.D. (Northwestern). American. Chemistry Department, Indiana University, Bloomington, Indiana, U.S.A. Professor of Chemistry. *Signed by :* V. J. Shiner, jun., M. Carmack.

Cherniak, Eugene Anthony, B.A. (Queen's). Canadian. 119, Alfred Street, Apt. 3, Kingston, Ontario, Canada. Graduate Student at Queen's University, Kingston. *Signed by :* J. K. N. Jones, W. MacF. Smith.

Cho, Arthur Kenji, M.S. (Oregon State Coll.). American. Department of Chemistry, University of California, Los Angeles 24, California, U.S.A. Graduate Student. *Signed by :* T. A. Geissman, R. E. Ireland.

Christie, Basil James Frederick, B.Sc. (Adelaide). British. Organic Chemistry Department, University of Adelaide, Adelaide, South Australia. Research Student. *Signed by :* G. M. Badger, H. J. Rodda.

Cohen, David. British. 36, Agecroft Road East, Prestwich, Manchester, Lancs. Undergraduate at Pembroke College, Cambridge. *Signed by :* F. G. Mann, R. N. Haszeldine.

Cox, Graham Frederick. British. 65, Walford Road, Uxbridge, Middlesex. Student. *Signed by :* J. Honeyman, A. J. B. Robertson.

Cross, Harry Roscoe, M.Sc. (Birm.), A.R.I.C. British. 69, Westwood Road, Salisbury, Wilts. Experimental Officer with the Ministry of Supply, Porton. *Signed by :* D. J. Marsh, A. H. Ford-Moore.

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Ducker, John William. British. Rose Cottages, Elmton Road, Creswell, Nr. Worksop, Notts. Student at Queen Mary College, London. *Signed by :* R. F. Garwood, M. J. S. Dewar.

Dyke, Stanley Frederick, B.Sc. (Lond.). British. 517, King Street, Aberdeen. Research Student at Aberdeen University. *Signed by :* K. W. Bentley, J. C. Ball.

Fielder, Ronald Sydney. British. 79, Camden Street, London, N.W.1. Student at Cambridge University. *Signed by :* F. G. Mann, R. N. Haszeldine.

Foster, John Michael. British. The Grammar School, Yarm, Yorks. Student at Emmanuel College, Cambridge. *Signed by :* F. G. Mann, R. N. Haszeldine.

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Hands, Anthony Richard. British. University College, Oxford. Undergraduate. *Signed by :* A. R. Katritzky, E. J. Bowen.

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Schwartzman, Louis Herbert, B.A. (The Johns Hopkins University), Ph.D. (Maryland). American. Koppers Company, Inc., Verona Research Center, Verona, Pennsylvania, U.S.A. Manager, Special Research Branch. *Signed by :* A. G. Renfrew, R. S. Tipson.

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Wilkinson, John. British. 31, Nest Estate, Mytholmroyd, Nr. Halifax, Yorkshire. Undergraduate at Leeds University. *Signed by :* E. G. Cox, E. Rothstein.

Yeh, Shou Yao. Chinese. Bentham Hall, Cartwright Gardens, London, W.C.1. Chemistry Student at University College, London. *Signed by :* E. D. Hughes, D. J. Millen, A. Maccoll.

Yukawa, Yasuhide, Dr.Sc. (Osaka). Japanese. 1-105, Dejimakaigan-dori, Sakai, Osaka, Japan. Professor of Organic Chemistry at Osaka University. *Signed by :* T. Sakan, S. Murahashi.

UNDER SPECIAL PROVISION APPERTAINING TO CANDIDATES RESIDENT ABROAD.

Appleton, Burton Lawrence, M.S. (New York). American. 60, South Munn Avenue, Apartment 615 East Orange, New Jersey, U.S.A. Chemist. *Signed by :* C. J. Verbanic.

Carrara, Gino, Dr.Chem. (Florence). Italian. Piazza Istria 8, Milano, Italy. Scientific Advisor. *Signed by :* G. Giacomello.

Goosen, André, B.Sc. (Natal). South African. Box 370, Pietermaritzburg, Natal, South Africa. Student. *Signed by:* F. L. Warren.

Holzman, George, B.S. and Ph.D. (Calif. Inst. Tech.). American. Shell Oil Co., 50, W. 50th Street, New York 20, N.Y., U.S.A. Chemist. *Signed by :* M. Nager.

Houtz, Ray Clyde, Ph.D. (Wisconsin). American. 400, Merchandise Mart, Chicago, Illinois, U.S.A. Research Director, The Toni Company. *Signed by :* W. P. Utermohlen.

Keppler, Herbert Harold, M.Sc. (Natal). South African. Natal Tanning Extract Co. Ltd., Pietermaritzburg, Natal, South Africa. Research Chemist. *Signed by :* F. L. Warren.

Matsumoto, Takeshi, B.Sc. (Hokkaido). Japanese. Chemistry Department, Hokkaido University, Sapporo, Japan. Assistant Professor of Organic Chemistry. *Signed by :* H. Suginome.

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PAPERS ACCEPTED

(List of Papers accepted between October 26th, 1955, and November 24th, 1955, for publication in the *Journal.*)

"Chemical action of ionizing radiations in solution. Part XV. Effect of molecular oxygen in the irradiation of aqueous benzene solutions with *X*-rays." By M. Daniels, G. Scholes, and J. Weiss.

"The S_N mechanism in aromatic compounds. Part XVI." By Brian A. Bolto, Mark Liveris, and Joseph Miller.

"Studies in peroxidase action. Part X. The oxidation of phenols." By H. BOOTH and B. C. SAUNDERS.

"Molecular polarisability. The apparent anisotropy of methane and other quasi-spherical molecules." By (MRS.) C. G. LE FÈVRE, R. J. W. LE FÈVRE, and D. A. A. S. NARAYANA RAO.

"Compounds containing directly-linked pyrrole rings. Part I. A new type of pyrrole pigment." By J. A. ELVIDGE, JOHN S. FITT, and R. P. LINSTEAD.

"The preparation and properties of some plutonium compounds. Part II. *X*-Ray diffraction studies of plutonium hydride." By B. J. MCDONALD and J. B. FARDON.

"A new synthesis of fluoro-ketones." By A SYKES, J. C. TATLOW, and C. R. THOMAS.

"Liquid-phase reactions at high pressures. Part X. The rates of some isomerisations and rearrangements." By R. T. HARRIS and K. E. WEALE.

"The stereochemistry of the tropane alkaloids. Part VIII. The absolute configurations of the nitrogen atoms in some optically active tropanols and derived quaternary salts." By ÖDÖN KOVÁCS, GÁBOR FODOR, and MIKLÓS HALMOS.

"Electrophilic substitution. Part I. Preliminary investigations." By P. M. G. BAVIN and M. J. S. DEWAR.

"2-Mercaptoglyoxalines. Part X. The acylation of 2-mercaptoglyoxalines." By ALEXANDER LAWSON and H. V. MORLEY.

"The pyrolysis of 1-benzylbenzotriazole and some homologues thereof." By M. S. GIBSON.

"Structure of a by-product in the formation of ascaridole glycol anhydride." By A. H. BECKETT and G. O. JOLLIFFE.

"An ion-sieve reagent for cæsium–alkali-metal separations." By R. M. BARRER and D. C. SAMMON.

"Infrared spectra of natural products. Part V. The characterisation of carbonyl groups in pentacyclic triterpenoids." By A. R. H. COLE and D. W. THORNTON.

"The ring fission of *iso*quinoline–sulphur trioxide." By K. T. POTTS.

"A new mechanism for the Beckmann rearrangement of ketoximes." By HENRY STEPHEN and BENJAMIN STASUN.

"Syntheses in the quinazolone series. Part I. Synthesis of 2 : 3-diaryl-4-quinazolones." By PAUL R. LEVY and HENRY STEPHEN.

"The calculation of atom self-polarisabilities and similar quantities in the molecular-orbital theory." By R. D. BROWN.

"New thiosemicarbazones and 4-oxo-Δ^2-thiazolin-2-ylhydrazones." By NG. PH. BUU-HOÏ, NG. D. XUONG, and F. BINON.

"Tracer studies in the formation and reactions of organic peracids." By C. A. BUNTON, (the late) T. A. LEWIS, and D. R. LLEWELLYN.

"The epimeric (±)-1 : 3-diamino*cyclo*hexanes." By F. R. HEWGILL and P. R. JEFFERIES.

"The preparation of some *iso*quinoline derivatives." By M. S. GIBSON.

"α-Methyleneadipic acid and some related compounds." By L. N. OWEN and A. G. PETO.

"2-Chloro-5-(α-halogenoacylamido)-7-methoxyacridines." By M. NEEMAN.

"Organic peroxides. Part VI. A stereochemical investigation of the preparation and reactions of 1-phenylethyl hydroperoxide." By ALWYN G. DAVIES and R. FELD.

"Attempted synthesis of 1 : 9-9' : 1'-dicarbazolylene." By ANN C. GEALE, JUNE M. G. LINNELL, and MURIEL L. TOMLINSON.

"Metal derivatives of *NN'*-diarylamidines." By WILLIAM BRADLEY and IAN WRIGHT.

"Theoretical studies of the macrocyclic pigments. Part I. The structure of bacteriochlorophyll." By J. R. BARNARD and L. M. JACKMAN.

"The reactions of anthracene and 9-methylanthracene with the free radicals derived from di-*tert.*-butyl peroxide." By A. L. J. BECKWITH and WILLIAM A. WATERS.

"The oxidation of *iso*butyraldehyde with the free radical, potassium nitrosyl sulphonate, $\cdot O \cdot N(SO_3K)_2$." By G. D. ALLEN and WILLIAM A. WATERS.

" Stages in oxidations of organic compounds by potassium permanganate. Part VII. Characteristic features of oxidations involving the manganate, MnO_4^{2-}, and hypomanganate, MnO_4^{3-}, anions." By J. S. F. Pode and William A. Waters.

" The retardation of benzaldehyde autoxidation. Part VII. Further studies of the actions of polycyclic aromatic hydrocarbons." By A. H. Turner and William A Waters.

" Polyazanaphthalenes. Part III. Some derivatives of 1 : 3 : 5- and 1 : 3 : 8-triazanaphthalene." By V. Oakes, R. Pascoe, and H. N. Rydon.

" The kinetics of the reduction of some azo-compounds." By N. R. Large and Sir Cyril Hinshelwood.

" Studies on phosphorylation. Part XIII. Ketoxime sulphonates as intermediates in pyrophosphate formation." By G. W. Kenner, Sir Alexander R. Todd, and R. F. Webb.

" *o*-Mercapto-azo-compounds. Part X. Reactions of azobenzene-2-sulphenyl bromide and its derivatives with malonic acid, acetone, and acetophenone." By A. Burawoy and A. Chaudhuri.

" *o*-Mercapto-azo-compounds. Part XI. Action of alkali on azobenzene-2-sulphenyl bromide and its derivatives." By A. Burawoy and A. Chaudhuri.

" The deuteration and exchange of ethylene on evaporated metal catalysts at low temperatures." By Charles Kemball.

" Thermodynamics of ion association. Part II. Alkaline-earth acetates and formates." By G. H. Nancollas.

" Analogues of cortical hormones." By Edward R. Clark and J. G. B. Howes.

" The preparation of benziminazoles from α-benzamido-acids and peptides." By R. Crawford and J. T. Edward.

" The synthesis and reactions of 3-*iso*hexyl-3-methyl*cyclo*hexanone." By (Miss) Usha Rakshit, K. C. Bhattacharyya, and J. C. Bardhan.

" Bis-2 : 4-diaminophenyl sulphone, and a new synthesis of 2 : 8-diaminophenothiazine 5 : 5-dioxide." By Helena Bradbury and F. J. Smith.

" Studies on degraded esparto cellulose." By G. O. Aspinall and W. B. Fordyce.

" An examination of the Rutaceae of Hong Kong. Part I. Flavonoid glycosides from *Zanthoxylum* species and the occurrence of optically active hesperetin." By H. R. Arthur, (Miss) W. H. Hui, and (in part) C. N. Ma.

" The Si–$C_{aromatic}$ bond in polyphenylsilyl compounds. The acid strengths of the series of acids *p*-$Me_{4-n}Ph_{n-1}Si{\cdot}C_6H_4{\cdot}CO_2H$." By J. Chatt and A. A. Williams.

" Polynuclear heterocyclic systems. Part I. The synthesis of condensed glyoxalinium salts." By B. R. Brown and E. H. Wild.

" Some basic esters of 9-xanthenylacetic acid." By (Miss) R. J. McConnel, V. Petrow, and B. Sturgeon.

" The synthesis of glucosamine 6-(dihydrogen phosphate)." By J. M. Anderson and Elizabeth Percival.

" Reduced cyclic compounds. Part I. The preparation and *cyclo*dehydration of ω-phenyl unsaturated tertiary alcohols." By M. F. Ansell and M. E. Selleck.

" Steroids and Walden inversion. Part XXIX. The configurations of the bromination products of 7-oxocholestan-3β-yl acetate." By D. R. James and C. W. Shoppee.

" Kinetics of the reaction between methyl iodide and trimethylamine in carbon tetrachloride solution." By R. B. Fahim and E. A. Moelwyn-Hughes.

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